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THE VARIABLE STAR 1921 *W AURIGAE.*

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THE variability of this star was discovered by Madame Ceraski from photographs taken by Blajko at the Moscow Observatory.[1] It was found to be 8.9 magnitude (evidently near maximum) in March and April 1898, but in October of the same year it was invisible in a "7-foot" telescope. Blajko[2] has published a summary of photographic and visual observations from 1895 to 1900, deducing from them a period of 0.75 year. In column 295 of this summary the *minimum* attributed to the writer should read *maximum*. Hartwig[3] has published a note on the place of the variable, but his conclusion in regard to the period, "somewhat greater than a year," is not in accord with the results of this paper. Esch[4] has published a note containing a few observations in February and March 1902, which are in good agreement with the light-curve shown in Fig. 2. Provisional results from the observations of 1898 to 1900 have been published by the writer,[5] with charts and approximate magnitudes of the comparison stars.

[1] *Astronomische Nachrichten*, **148**, 15, 1898.

[2] *Ibid.*, **153**, 295, 1900.

[3] *Ibid.*, **149**, 6, 1899.

[4] *Ibid.*, **160**, 335, 1902.

[5] ASTROPHYSICAL JOURNAL, **12**, 54, 1900; **14**, 171, 1901; *Astronomical Journal*, **20**, 6, 1899; *Popular Astronomy*, **7**, 43, 1899; **8**, 461, 1900.

POSITION OF THE VARIABLE.

The variable was connected on three nights with the star *c*, which is *B.D.*+36° 1141, and whose place is:

	R. A.	Dec.	
	h m s		
From the Lund *A. G.* Catalogue	5 19 00.47	+36° 43′ 28″.7	(1875)
	5 20 41.84	+36 44 56.1	(1900)
Difference, *variable–c*	–0 33.28	–3 56.8	
Place of the *variable*	5 20 08.56	+36 48 52.9	(1900)

As the last decimal place should be discarded, the result can be stated:

	h m s		
1921 W Aurigae	5 20 08.6	+36° 48′ 53″	(1900)
	5 17 06.0	+36 46 11	(1855)

This place agrees closely with that given by Hartwig in the reference above cited.

INSTRUMENTS.

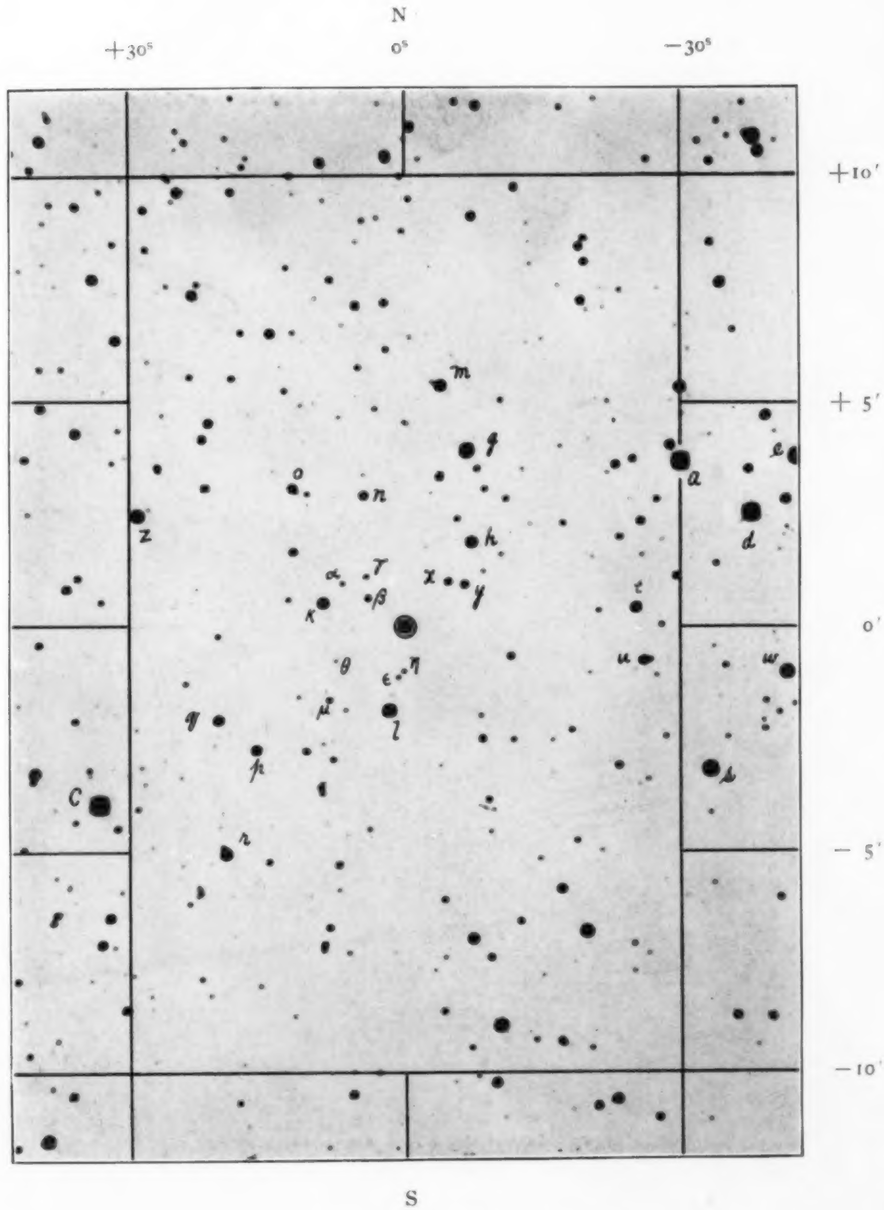
These are the same as described in the two preceding papers of this series,[1] a 157 mm (6.2-inch) reflector, a 305 mm (12-inch) refractor, and the 101 cm (40-inch) refractor, the equalizing wedge photometer used in the photometric work being attached to each of these instruments. In the photometric measures of the brighter standard stars with the 12-inch telescope an absorption glass was interposed in the cone of rays from the objective. The adopted value of the absorption, 1.70 magnitudes, depends upon a series of laboratory measures and also on measures of *Pleiades* stars, but further measures may change it a few hundredths of a magnitude.

THE CHART.

Plate XIII shows the field 18′ × 24′ around the variable, on a scale of 10″ to the millimeter. The negative was taken with the 24-inch reflector January 11, 1902, exposure from $6^h\ 0^m$ to $6^h\ 55^m$, Central Standard Time, and shows stars to the sixteenth magnitude distinctly; but as the fainter stars were not used in the comparisons, the print for the cut was made to show stars only

[1] "The Variable Star *X Cephei*," ASTROPHYSICAL JOURNAL, **17**, 48, 1903; "The Variable Star *V Lyrae*," *ibid.*, **18**, 33, 1903.

PLATE XIII.



1921 *W AURIGAE*

($5^h\ 20^m\ 8^s.6$; $+36°\ 48'\ 53''$)

to the fifteenth magnitude. The strong color of the variable is shown by the fact that the photographic magnitude is about 10.9, the diameter of the disk being between that of *g* and *l*. The light-curve shows that the variable was near maximum, probably about 9.5 magnitude visually at this time.

COMPARISON STARS.

The three standard stars on which are based the measures of the comparison stars are as follows:

TABLE I.

Star	*B. D.*				Magnitudes		
	No.	Mag.	Position for 1855		Potsdam		Harvard 45
			R. A.	Dec.	Color	Mag.	Mag.
			h m s				
A....	+37° 1160	7.2	5 12 42.0	+37° 31′.8	GW–	7.63	7.39
B....	+36 1122	6.8	5 14 59.4	+36 3.6	G–	6.60	6.74
C....	+36 1113	6.8	5 14 5.7	+36 15.1	GW	6.98	6.90
					Mean	7.07	7.01

Of the stars used for visual comparisons with the variable, the following are in the *Durchmusterung:*

TABLE II.

Star	No.	Mag.	1855	
			R. A.	Dec.
			h m s	
e	+36° 1133	9.5	5 16 22.6	+36° 49′.9
s	+36 1134	9.5	5 16 30.4	+36 42.9
a	+36 1138	9.5	5 16 35.8	+36 50.3
c........	+36 1141	8.9	5 17 40.0	+36 42.6
b........	+36 1145	9.2	5 18 13.9	+36 58.1
m′......	+36 1147	9.2	5 18 19.2	+36 53.2
o′.......	+37 1200	8.5	5 18 23.5	+37 6.2

The date for the remaining comparison stars are given in the following table:

TABLE III.

COMPARISON STARS FOR *W AURIGAE.*

(IN ORDER OF RIGHT ASCENSION.)

Star	Co-ordinates from *V* R. A.	Co-ordinates from *V* Dec.	Light Scale	Magnitude Measured	Magnitude From Curve	Star	Co-ordinates from *V* R. A.	Co-ordinates from *V* Dec.	Light Scale	Magnitude Measured	Magnitude From Curve
	s		steps				s		steps		
f....	−47	+5′ 42″	....	.....	.....	*l*...	+ 2	− 1′ 51″	25.4	10.94	.....
e....	−43	+3 48	33.8	.....	10.0	*β*..	+ 4	+ 0 37	9.1	13.58	.....
w...	−42	−0 57	20.4	.....	11.93	*γ*..	+ 4	+ 1 6	4.9	14.25	.....
d...	−38	+2 28	....	.....	.....	*n*..	+ 4	+ 2 58	20.3	.....	11.94
s....	−34	−3 5	31.3	.....	10.35	*α*...	+ 7	+ 0 56	9.8	13.65	
a...	−30	+3 19	33.3	10.35	.....	*θ*...	+ 8	− 0 47	6.7	14.13	.....
t....	−26	+0 26	19.3	.....	12.10	*μ*...	+ 8	− 1 39	11.3	13.39	.....
u...	−26	−0 43	18.3	.....	12.26	*k*...	+ 9	+ 0 30	25.9	11.17	.....
h...	− 7	+1 46	21.9	11.60	.....	*o*...	+12	+ 2 58	....	.....	.....
g...	− 7	+3 50	29.2	10.79	.....	*p*...	+16	− 2 37	22.0	.....	11.73
y....	− 7	+0 56	17.1	12.42	.....	*r*...	+19	− 4 59	20.9	.....	11.89
x...	− 5	+0 56	15.5	12.63	....	*q*...	+20	− 2 1	22.3	.....	11.67
m...	− 4	+5 20	22.9	.....	11.62	*z*...	+29	+ 2 48	28.9	.....	10.73
η....	− 0	−0 56	0.0	14.12	.....	*c*...	+33	− 3 57	37.2	9.58	.....
ε....	+ 1	−1 8	2.3	14.34	.....	*m′*.	+73	+ 7 0	38.4	.....	9.37
						o′..	+77	+20 0	42.9	.....	8.70

TABLE IV.

PHOTOMETRIC MEASURES OF COMPARISON STARS.

1902, January 24; 12-inch. Wedge V, seeing good, full Moon.

Star	Scale Readings: First			Scale Readings: Second			Mean Scale Reading	Magnitude
Aa.....	23.7	24.2	23.3	23.8	23.0	23.0	23.50	**7.63**
Ca.....	15.3	15.0	16.0	15.0	15.8	15.8	15.48	**6.98**
Ba....	14.5	13.2	13.8	13.2	11.2	12.2	13.02	**6.60**
a......	34.1	35.0	35.0	35.2	33.4	35.0	34.45	10.66
g......	37.8	39.2	38.2	34.8	34.2	34.0	36.37	10.87
h......	43.3	42.0	41.3	42.2	42.2	43.2	42.37	11.54
k......	38.2	38.9	39.1	39.8	39.1	39.9	39.17	11.18
l......	38.2	38.2	37.0	40.2	39.7	40.8	39.02	11.17
v......	29.5	28.8	28.7	....	....	....	29.00	9.95

Wedge constant, 0.110 mag.

TABLE IV.—*Continued.*

1902, February 7; 12 inch. Wedge V, seeing good.

Star	Scale Readings						Mean Scale Reading	Magnitude
	First			Second				
Aa.....	18.8	17.5	17.8	....	....	....	18.37	**7.63**
Ca.....	12.0	12.8	13.2	....	....	....	12.67	**6.98**
Ba....	9.2	10.7	10.2	....	....	....	10.03	**6.60**
a......	27.7	27.4	26.2	....	....	....	27.10	10.25
g......	32.1	32.2	32.2	....	....	....	32.17	10.80
h......	37.0	39 4	39.0	....	....	....	38.47	11.50
k......	34.5	33.7	34.0	....	....	....	34.07	11.01
l......	32.1	31.1	31.0	....	....	....	31.40	10.72

Wedge constant, 0.110 mag.

1903, January 1; 12-inch. Wedge V, seeing good.

Star	First			Second			Mean Scale Reading	Magnitude
A......	14.7	12.0	12.8	....	....	....	13.17	**7.63**
Ba....	19.0	21.2	19.8	....	....	....	20.00	**6.60**
C.....	7.3	4.1	4.7	....	....	....	6.16	**6.98**
Ca....	21.4	23.1	22.0					
a......	37.8	38.0	38.8	37.2	37.3	37.7	37.80	10.35
g......	43.0	44.5	43.1	38.8	42.8	41.7	42.32	10.85
h......	52.9	49.4	51.4	50.1	49.9	50.0	50.62	11.76
k......	47.2	48.0	47.8	45.9	46.1	45.3	46.72	11.33
l......	44.8	45.8	45.3	43.0	42.3	42.8	44.00	11.03

Wedge constant, 0.110 mag.

1903, March 21; 6-inch. Wedge V, seeing fair.

Star	First			Second			Mean Scale Reading	Magnitude
B.....	11.5	11.3	11.7	12.4	12.5	12.3	11.95	**6.60**
C......	15.8	16.2	15.9	16.1	15.3	16.3	15.94	**6.98**
A......	22.2	22.0	22.3	20.6	21.7	21.7	21.75	**7.63**
a......	47.7	47.8	48.2	45.7	46.5	45.7	46.94	10.41

Wedge constant, 0.110 mag.

1903, March 22, 6-inch. Wedge V, seeing good.

Star	First			Second			Mean Scale Reading	Magnitude
B.....	14.0	13.8	13.4	13.6	15.0	14.7	14.08	**6.60**
C......	17.0	15.7	16.2	17.7	18.5	18.2	17.22	**6.98**
A......	23.2	22.6	23.2	21.5	22.7	21.5	22.45	**7.63**
a......	45.5	45.5	44.7	43.3	43.7	43.0	44.28	9.97
g......	49.6	49.4	49.8	51.2	50.9	51.2	50.35	10.64
c......	40.8	39.0	39.7	40.9	40.9	40.4	40.78	9.58

Wedge constant, 0.110 mag.

TABLE IV.—*Continued.*

RESULTING MAGNITUDES, FROM MEASURES WITH 6- AND 12-INCH.

	1902 January 24	1902 February 7	1903 March 1	1903 March 21	1903 March 22	Means
c........	.....	.....	.....	.....	9.58	9.58
a........	10.66	10.25	10.35	10.41	9.97	10.35
h........	11.54	11.50	11.76	.....	.....	11.60
g........	10.87	10.80	10.85	.....	10.64	10.79
k........	11.18	11.01	11.33	.....	... .	11.17
l........	11.17	10.72	11.03	.....	.....	10,94

1900, October 23; 40-inch. Wedge II, seeing fair.

Star	Scale Readings						Mean Scale Reading	Magnitude
	First			Second				
k......	15.9	16.7	17.2	19.0	17.9	16.8	17.25	**11.17**
h......	21.0	19.9	21.8	21.9	22.7	22.0	21.55	**11.60**
g......	13.2	15.0	15.9	14.0	15.5	14.0	14.60	**10.79**
l......	17.1	17.8	17.0	19.8	19.2	19.9	18.47	**10.94**
α......	40.2	41.1	39.9	37.3	37.9	37.5	38.98	13.63
γ......	46.7	46.4	42.8	39.3	41.8	41.1	43.02	14.21
β......	40.8	39.5	38.0	38.9	38.2	37.0	38.73	13.60
θ......	42.7	40.9	40.0	42.2	44.1	42.8	42.12	14.06
μ......	38.2	37.1	36.1	34.5	35.0	35.0	35.98	13.24
ε......	43.8	46.0	44.2	45.9	46.4	45.0	45.22	14.44
η......	42.5	43.7	43.4	41.8	43.5	41.0	42.65	14.11
x......	30.0	29.4	30.1	30.0	31.8	32.1	30.58	12.54
y......	25.2	28.8	25.8	28.0	27.0	26.0	26.80	12.05
δ......	32.9	31.0	31.0	29.9	32.0	31.2	31.33	12.64
v......	34.2	33.0	31.5	34.0	31.9	33.9	33.09	12.79

Wedge constant, 0.130 mag.

1902, February 4; 40-inch. Wedge V, seeing good.

k......	10.0	10.0	9.2	11.1	10.9	11.8	10.50	**11.17**
l......	10.8	11.3	11.1	10.2	12.2	11.3	11.15	**10.94**
ha.....	26.6	28.3	26.1	....	....	....	27.00	**11.60**
ga.....	18.3	19.9	18.9	....	....	....	19.03	**10.79**
μ......	30.3	31.0	31.0	....	....	....	30.77	13.47
θ......	37.7	38.7	37.3	....	....	....	37.90	14.26
ε......	37.8	38.4	38.6	....	....	....	38.27	14.30
β......	30.5	31.6	31.3	....	....	....	31.13	13.51
γ......	37.3	38.0	38.3	....	....	....	37.87	14.26
α......	33.6	32.6	32.3	....	....	....	32.83	13.70
x......	20.9	22.0	23.0	....	....	....	21.97	12.51
y......	22.0	21.0	20.8	....	....	....	21.27	12.43

Wedge constant, 0.110 mag.

TABLE IV.—*Continued.*

1902, February 6; 40-inch. Wedge V, seeing fair.

Star	Scale Readings						Mean Scale Reading	Magnitude
	First			Second				
ha.....	35.2	35.0	35.1	33.8	34.0	33.0	34.35	**11.60**
ka.....	27.5	26.3	26.0	....	....	....	26.60	**11.17**
la.....	29.4	29.2	29.3	28.0	27.1	27.2	28.37	**10.94**
y.....	27.8	29.0	28.2	....	....	....	28.33	12.78
x......	29.1	28.6	29.1	....	....	....	28.93	12.85
β......	35.2	35.8	36.8	....	....	....	35.93	13.62
γ......	42.0	42.0	42.3	....	....	....	42.10	14.30
α......	36.5	36.0	35.5	....	....	....	36.00	13.63
θ......	40.5	40.0	39.5	....	....	....	40.00	14.07
μ......	34.0	34.2	35.2	....	....	....	34.47	13.45
ε......	41.2	43.0	41.8	....	....	....	42.00	14.29

Wedge constant, 0.110 mag.

RESULTING MAGNITUDES, FROM MEASURES WITH 40-INCH.

	1900 October 23	1902 February 4	1902 February 6	Means
x......	12.55	12.51	12.85	12.63
y......	12.05	12.43	12.78	12.42
α......	13.63	13.70	13.63	13.65
β......	13.60	13.51	13.62	13.58
γ......	14.20	14.26	14.30	14.25
δ.....	12.65	.....	.....	12.65
ε......	14.44	14.30	14.29	14.34
θ......	14.06	14.26	14.14	14.13
η......	14.12	.....	.....	14.12
μ......	13.26	12.47	13.45	13.39

The photometric measures of the comparison stars are given in Table IV, which is arranged similarly to the corresponding table in the two previous papers. The stars used as standards are given first with their magnitudes in ***bold-faced*** type. The magnitudes for *A*, *B*, and *C* are taken from Table I, using the Potsdam values; to reduce to the Harvard scale subtract 0.06 from the numerical magnitude. The values for the fainter standards, lettered from *a* to *l*, are taken from the part of Table

TABLE V.

1921 W Aurigae.

(Comparisons of the Variable by Argelander's Method.)

No.	Date				Ocular	Aperture	Comparisons
	Month	Day	Hour	Julian Day			
	1898		C.S.T.	G. M. T. 2410000+			
1	Dec.	10	6	4634.5	40	6	o' 4 v, c 2 v, v 1 a
					80	6	c 1 v, v 1 a
2		12	18	4637.0	40	6	c 0-1 v, v 2 a
3		13	7	4637.5	40	6	m' 2 v, v c, v 1 b
4		15	8	4639.6	40	6	m' 1 v, v 2 b, v 0-1 c
5		17	7	4641.5	40	6	m' 1 v, v c, v 3-4 a
			8	4641.6	80	6	v 1 c
6		22	6	4646.5	40	6	v 2 b, m' 0-1 v, v 1 c, v 4 a
7		26	8	4650.6	40	6	v 2 c, v m', o 5 v
8		28	8	4652.6	80	6	c 0-1 v
9		30	7	4654.5	40	6	c 1 v
	1899						
10	Jan.	5	6	4660.5	40	6	v 0-1 c
11		10	7	4665.5	150	6	c 2-3 v, v 3-4 a
					40	6	c 1-2 v, v 3 a
13		18	7	4673.5	150	6	c 4 v, v 1 a
					40	6	c 3 v, v 0-1 a
14		24	7	4679.5	40	6	c 4 v, a 2 v
					150	6	c 4-5 v, a 2 v, v s, v 3-4 g
15		28	7	4683.5	150	6	c 6 v, a 2 v, s 1 v, v 3 g
16	Feb.	1	7	4687.5	150	6	a 4 v, c 4 v, s 2 v, v 2 g, v 3 l
17		15	7	4701.5	150	6	s 5 v, g 2-3 v, l 1 v, v 0-1 k, v 4-5 h
18		28	8	4714.6	150	6	h 1-2 v, v 2 n, v 3 y
19	Mar.	6	8	4720.6	150	6	h 2 v, v 2 y
20		13	8	4727.6	150	6	n 2-3 v, v 2 y, h 4 v
21		28	8	4742.6	150	6	y 2-3 v
22	Apr.	4	8	4749.6	200	6	y 1-2 x, x 2 v
23		12	8	4757.6	150	6	v not seen
24		28	8	4773.6	150	6	v not seen
25	May	4	8	4779.6	150	6	v not seen
26	Oct.	30	8	4958.6	40	6	a 1 v, v 2 s, v 2-3 g
					150	6	a 0-1 v, v 2 s, v 3 g
27	Nov.	4	8	4963.6	150	6	a 1 v, v 1 s, v 3 g
28		20	7	4979.5	150	6	g 3 v, v 2 l
29		26	7	4985.5	150	6	g 5 v, l 0-1 v, v 1-2 h
30	Dec.	5	7	4994.5	150	6	l 3 v, h 1 v, v 1 n, v 4 y
31		19	7	5008.5	150	6	h 2-3 v, v 1 n
32		28	7	5017.5	150	6	h 6 v±, v 0-1 n, v y, v 1 x
	1900						
33	Jan.	4	7	5024.5	200	6	y 1-2 v, v 1 x
34		8	6	5028.5	350	40	y 2 v, v 1 x
35		25	8	5045.6	175	12	x 5-6 v
36		26	10	5046.7	350	40	x 2-3 v, v 2-3 β
							β α, α 4 γ, γ 4 ε, ε 2 η
37	Feb.	4	11	5055.7	350	40	x 3-4 v, v 3-4 α
							x 5 α, α 2 β, β 6 γ, γ 1 ε, ε 2 η

TABLE V.

1921 W Aurigae.

(Reduction of Observations.)

No.	Details in Steps	Means: Steps	Means: Magnitudes	Seeing	Remarks
1	38.9, 35.2, 34.3 36.2, 34.3	35.7	9.74	good	
2	36.7, 35.3	36.0	9.68	fair, faint twilight	
3	36.4, 37.2, 36.6	36.7	9.59	good	
4	37.4, 37.6, 37.7	37.5	9.46	good	
5	37.4, 37.2, 36.8 38.2	37.6	9.64	good, Moon	
6	37.6, 37.9, 38.2, 37.3	37.2	9.50	good, Moon	
7	39.2, 38.4, 37.9	38.5	9.32	good, Moon	
8	36.7	36.7	9.59	poor	
9	36.2	36.2	9.67	fair	
10	37.7	37.7	9.43	fair to poor	
11	34.7, 36.8 35.7, 36.3	35.6	9.75	good	
13	33.7, 34.3 34.2, 33.8	34.0	9.97	good	
14	33.2, 31.3 32.7, 31.3, 31.3, 32.7	32.0	10.27	good, Moon	
15	31.2, 31.3, 30.3, 32.2	31.2	10.38	good	
16	29.3, 29.8, 29.3, 31.2	29.8	10.60	good	
17	26.3, 26.7, 24.4, 26.4, 26.4	26.0	11.13	good, Moon	
18	20.4, 22.3, 20.1	20.9	11.88	good	
19	19.9, 19.1	19.5	12.07	good	
20	17.8, 19.1, 17.9	18.2	12.27	good	
21	14.6	14.6	12.79	good	
22	13.5	13.5	12.94	fair to good	
23			<12.5	fair	limit *x* or *y*
24			<12.0	fair	limit *n*
25			<12.0	twilight	limit *n* and *o*
26	32.3, 33.3, 31.7 32.8, 33.3, 32.2	32.6	10.18	low, fair	
27	32.3, 32.3, 32.2	32.2	10.24	low, fair	
28	26.2, 28.4	27.3	10.96	poor	
29	24.2, 24.9, 22.4	23.8	11.47	fair	
30	22.4, 20.9, 21.3, 21.1	21.4	11.79	good	
31	19.4, 21.3	20.3	11.95	fair, Moon rising	
32	15.9, 20.8, 17.1, 16.5	17.5	12.37	good	
33	15.6, 16.5	15.8	12.58	small Moon	
34	15.1, 16.5, 15.8	15.8	12.61	Moon	
35	10.0	10.0	13.47	good	
36	13.5, 11.6	12.5	13.09		
37	13.5, 13.3	13.4	12.96		

TABLE V—*Continued.*

No.	Date				Ocular	Aperture	Comparisons
	Month	Day	Hour	Julian Day			
	1900		C.S.T.	G. M. T. 2410000+			
38	Feb.	18	10	5069.7	350	40	$v\ \alpha$, $v\ \beta$, v 5-6 γ, v 6 η x 6-8 v, v 1-2 α (2d comparison)
39		22	9	5073.6	350	40	α 2 v, β 2 v, v 3 γ, v 5 η α 1 v, β 1 v, v 4 γ, μ 2 β, β 3 θ
40		24	10	5075.7	175	12	v not seen
41	Mar.	1	8	5080.6	350	40	α 1-2 v, β 1-2 v, v 4 γ, v 1 θ, v 5 η
42		21	9	5100.6	275	12	v 1 β, μ 4 v, v 1 θ
43		22	9	5101.6	350	40	μ 3 v, v 1 θ, v 3 γ, β 1 v
44	Apr.	4	9	5114.6	275	12	μ 2 v, v 2 β
45		18	8	5128.6	275	12	y 2 v, v 1 x, v 2 μ
46		19	8	5129.6	275	12	v 2 μ, x 1 v, y 2-3 v, v 3 β
47		27	10	5137.7	350	40	$v\ y$, v 2 x, n 3 v
48		29	9	5139.6	150	6	v not seen
49	Aug.	30	19	5263.0	237	40	v 2 k, v 3 l
49*a*	Oct.	23	12	5316.8	237	40	
	1901						
50	Feb.	9	7	5425.5	150	6	v not seen
51		10	7	5426.5	150	6	v not seen
	1902						
52	Jan.	11	7	5761.5	...	24	
53		24	7	5774.6	67	12	
54	Feb.	6	10	5787.7	237	40	
	1903						
55	Jan.	1	8	6116.6	67	12	$v\ n$, h 5 v, v 4 x
56	Mar.	21	11	6195.7	80	6	v not seen

IV headed "Resulting Magnitudes from Measures with 6- and 12- Inch." The subscript $_a$ indicates that the star was measured through the absorption glass, before mentioned, which cuts down the light 1.70 magnitudes (equals 15.45 scale-divisions with wedge V). For the fainter stars, from x down, the average deviation of the separate night's result from the mean of the three is 0.09 magnitude. If the star y, for which the deviation is anomalous, be omitted, the average deviation becomes 0.07 magnitude.

MAGNITUDE-CURVE.

This is given in Fig. 1, platted with photometric magnitudes as abscissæ and positions in the light-scale as ordinates; giving the points shown by the round dots. In this case the "curve"

TABLE V—*Continued.*

No.	Details in Steps	Means		Seeing	Remarks
		Steps	Magnitudes		
38	9.8, 9.1, 9.4, 6.0 8.5, 8.3	8.5	13.67	fair	
39	7.8, 7.1, 7.9, 5.0 8.8, 8.1, 8.9	7.6	13.82	good	
40		<11.5	<13.25	fair	limit $4 < x$
41	8.3, 7.6, 8.9, 7.6	7.5	13.83	good	
42	10.1, 7.3, 7.7	8.3	13.70	good	limit θ or $1 < \beta$
43	8.3, 7.7, 7.9	7.9	13.77	good	limit $4 < \eta$
44	8.3, 11.1	9.7	13.50	good, Moon	
45	15.1, 16.5, 13.3	14.9	12.76	fair, thick	
46	13.3, 14.5, 14.6, 12.1	13.6	12.94	good	limit β
47	17.1, 17.5, 17.3	17.3	12.39	fair	
48			<12.0		limit n
49	27.9, 28.4	28.1	10.83	twilight	
49a			12.79	fair	photometer
50		<20.4	<11.8	fair	limit $1\text{-}2 < h$
51		<19.9	<12.0	fair	limit n
52			<10.9		photo. 55 m. exp.
53			9.95	good, Moon	photometer
54			10.22	fair to good	photometer
55	20.3, 16.9, 19.5	18.9	12.18	good	
56		<21.9	<11.6	good, low	limit h

is a straight line. The average distance of the dots from the line is 0.10 magnitude; omitting η, the distance is 0.08. The value of one step is 0.14 magnitude.

VISUAL OBSERVATIONS.

The visual comparisons of the variable by Argelander's method are given in detail in Table V. The light-scale was formed from them in the usual manner, giving the quantities in the fourth column of Table III. Table V also contains the results of three sets of photometric measures of the variable (observations No. 49_a, 53, and 54) and the magnitude determination from the photograph (No. 52).

LIGHT-CURVE.

In Fig. 2 the observed magnitudes from 1898 to 1903 are platted and the light-curve drawn through them; the parts of the curve covered by the observations being drawn full, while

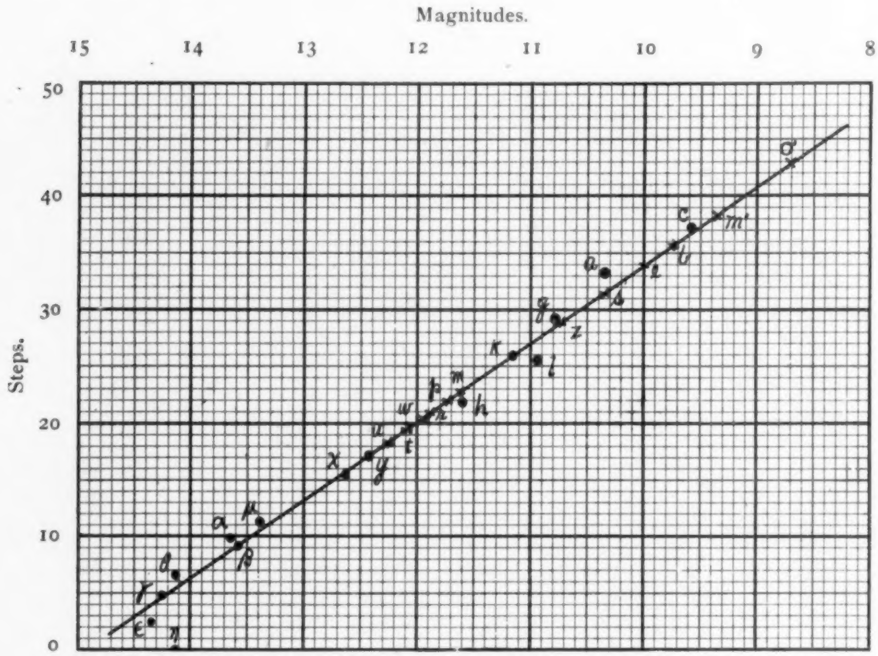


FIG. 1.—Magnitude Curve of *W Aurigae*.

the parts assumed, in absence of sufficiently numerous observations, are drawn with a broken line. The variations seem best represented by the elements of maximum —

1898, December 24 (J. D. 2414648) + 276 E (M-m=113)

Magnitudes: Max. 9.3, Min. 13.8.

In Table VI are collected the dates of maximum and minimum, together with a comparison with the observations given in Blajko's summary previously quoted, from the *Nachrichten*.

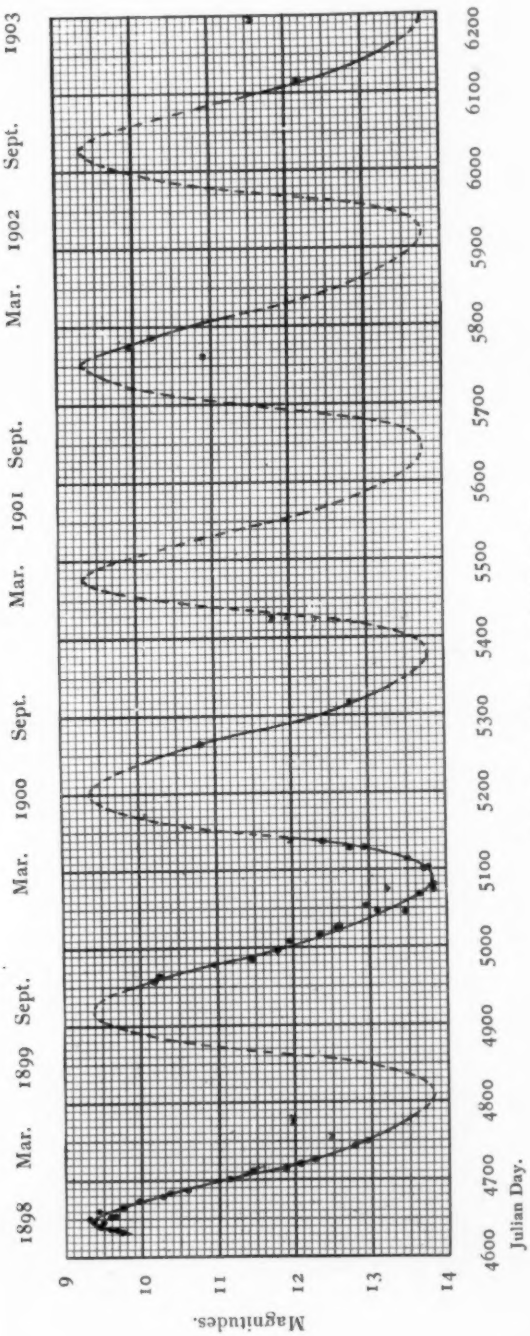


FIG. 2.—Light-Curve of *W Aurigae*.

TABLE VI.

MAXIMA.

Epoch	Calculated		Observations Blajko's Summary		Blajko's Maxima
	Julian Day	Calendar	Date	Magnitude	
	2410000+				
−5	3268	1895, Mar. 15	1895, Feb. 15	10.1 ph	March or April
			1895, Mar. 4	9.3 ph	
−4	3544	1895, Dec. 16	1895, Dec. 16	8.8 ph	December
			1895, Dec. 21	8.8 ph	
−3	3820	1896, Sept. 17			
−2	4096	1897, June 20			
−1	4372	1898, Mar. 23	1898, Apr. 10	9.2 vis	
			1898, October	< 12 vis	
0	4648	1898, Dec. 24	1899, Feb. 21	11 vis	December
			1899, Mar. 31	< 12 vis	
1	4924	1899, Sept. 26	1899, October	10 to 11 vis	
			1899, Dec. 28	12 ± ph	
2	5200	1900, June 29	1900, April	12 vis	Second part of June
3	5476	1901, Apr. 1			March
4	5752	1902, Jan. 2			
5	6028	1902, Oct. 5			

MINIMA.

Epoch	Calculated		Observations Blajko's Summary	
	Julian Day	Calendar	Date	Magnitude
	2410000+			
−4	3431	1895, Aug. 25		
−3	3707	1896, May 27		
−2	3983	1897, Feb. 27	1897, Mar. 26	< 12 ph
−1	4259	1897, Nov. 30	1898, Jan. 16	< 12 ph
0	4535	1898, Sept. 2	1898, October	< 12 ph
1	4811	1899, June 5	1899, Apr. 4	< 12 ph
			1899, Apr. 6	< 12 ph
2	5087	1900, Mar. 8		
3	5363	1900, Dec. 9		
4	5639	1901, Sept. 11		
5	5915	1902, June 14		
6	6191	1903, Mar. 17		

In the column of "Observations," "ph" stands for "photographic" and "vis" for "visual." It will be seen that the above elements satisfy the observation between 1895 and 1903. The

calculated dates of maxima and minima are well represented by the light-curve, though the observations are not sufficiently numerous to enable us to detect variations of less than fifteen or twenty days with certainty. The magnitudes on the photographs near the maximum at epoch -4 do not agree very closely with my photograph taken near maximum at epoch $+4$ (indicated on the light curve, Fig. 2, by the small cross), but doubtless a large part of the divergence can be accounted for by the use of different photographic plates.

YERKES OBSERVATORY,
September 1903.

ON CERTAIN METHODS OF ECONOMIZING THE LIGHT IN SPECTRUM ANALYSIS.

By W. J. HUMPHREYS.

NO MATTER what the source of light nor what kind of spectrograph is used to analyze it, there are distinct advantages in obtaining its spectra as brilliant as possible. In this way lines are found that otherwise would escape detection, and photographs, which of course integrate the light during the time of exposure, are obtained more quickly, and therefore under more nearly uniform conditions. Moreover, such economy is desirable in obtaining spectrograms of very volatile substances, small amounts of any material, arcs under pressure, and other temporary sources of light. Again, it renders practical the use of instruments of correspondingly larger dispersive powers — an advantage of the utmost value in nearly every line of spectrum work.

The above are some of the reasons why a spectrograph should be equipped with light-saving devices, and in what follows I shall briefly describe a few of these, most of which have been fully tested experimentally.

I. ILLUMINATION OF THE SLIT.

Assuming that the source of light is not under the experimenter's control, or if so, that its intensity has been pushed to the practicable limit — in short, with a fixed source, — probably the most obvious method of increasing the brilliancy of its spectrum, as produced by a given instrument with a definite adjustment, is that of increasing the illumination of the slit.

If the source is so far away that it appears as a point, a star for instance, or line, like the disappearing crescent of the Sun at a total solar eclipse, then it is quite feasible, as is generally known, to discard the slit entirely and use an objective-prism or grating; but for obvious practical reasons it is the custom, when working with large instruments, to focus the light with convex

refractors or concave reflectors upon a suitable slit, though such a procedure is necessarily beset with difficulties. Large refractors have to be made of glass, and are therefore more or less opaque to the ultra-violet, while the light that gets through is always in some measure dispersed by chromatic aberration. Reflectors, on the other hand, are free from chromatic aberration, but even though perfectly figured, if they consist of speculum metal, return scarcely two-thirds of the incident visible light and barely two-fifths of the ultra-violet; while, if silver on glass is used, nearly all the ultra-violet is lost.[1] With such sources the only means, appliable to all types of spectrographs, that has occurred to me of increasing the illumination of the slit, when the size of the apparatus is fixed, is by the use of properly selected reflectors, silver for the visible light and magnalium, wherever practicable, for the ultra-violet. A special method adapted to concave gratings will be described further on.

When a flame, electric arc, or other near-by source is used, the problem is radically different from the preceding one, where it was supposed to be far off. Here, by merely placing the source in front of the slit, a fair amount of light is caused to reach the grating or other analyzer—an amount which, if the source is uniformly brilliant throughout, is independent of its distance so long as the cone of light passing through the slit is large enough to cover the analyzing surface; and to the end that this cone shall be of ample size it is customary to use an ordinary condensing lens, commonly consisting of quartz for gratings to secure the ultra-violet, with the slit and source at its conjugate foci. When the light is intense and constant, this method is sufficient for most purposes. It also has the great advantage, when prisms or flat gratings are used, of giving the distribution in the arc or other source, of the substances producing the spectra. It has, however, besides the loss of some light by reflection, the disadvantage of chromatic aberration, by virtue of which the relative intensities of the colors are not the same at the analyzer that they are in the source.

Of course, the sharper the image on the slit, as produced by

[1] HAGEN and RUBENS, *Annalen der Physik*, **8**, 1–21, 1902.

any one color, the greater the amount of that kind of light that reaches the analyzer; but so long as the slit is kept in one of the foci, and the cone of light from it fully covers the analyzing surface, there is but little to be gained by altering the position, size, or focal length of the condensing lens. In the case of concave gratings, however, and in general where the distribution of the light in the source is not under consideration, it is easy to increase greatly the brilliancy of the spectrum by the use of suitable concave reflectors.

a) As the most general type of such reflector it is convenient to consider a portion of an ellipsoid of revolution. Let this be adjusted so that the center of the source of light, say sparks between metallic points, shall be in one focus, and the slit, which should be parallel to the line joining the spark terminals, in the other focus of the ellipsoid, whose inner surface is supposed to be a highly polished good reflector. The line joining the foci should, of course, if prolonged, intersect the center of the prism or grating. By this means the light that fills a large solid angle whose vertex is at the source, is converged upon the slit, and, by adapting the dimensions of the ellipsoid to the spectrograph in use, much of it is made to reach the analyzer. This method evidently would avoid chromatic aberration, as well as utilize a larger amount of light than could be secured by means of a lens.

b) If the foci of the ellipsoid are separated until the figure becomes a paraboloid of revolution, with the source centered in the focus, the rays of reflected light become approximately parallel and may be condensed upon the slit with a suitable lens; or by placing the slit in the focus and close to the source, but between it and the parabolic reflector, the parallel rays thus obtained would be adapted to an objective concave grating or other analyzer requiring the use of a collimator. Of course, the disturbing light from the source would have to be screened off from the instrument, and this could be done by a small opaque object suitably placed; or, among other ways, the source might be put quite to one side and, by the aid of a condenser and small optical flat mirror, a brilliant image formed on the slit.

But the ellipsoid and paraboloid, while simple enough in

theory, are necessarily difficult to make, and therefore expensive; still they are mentioned in this connection because of their decided value, if properly constructed, and, further, they naturally belong with a third method described below, which is exceedingly easy of construction, inexpensive, and efficient.

c) Again, considering the ellipsoid of revolution, let its foci be brought closer together, till they finally coincide, and the surface becomes spherical. In this case the source, which is at the center of the sphere, and its image are superimposed, and the condensing lens in front of the slit receives both the direct and the reflected light. Evidently the source could be placed

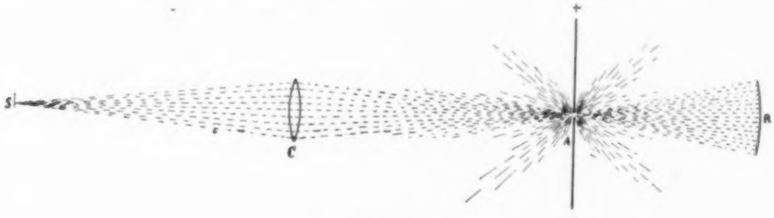


FIG. 1.

slightly to one side, and its reflected image alone received upon the slit. The particular advantage, that might occasionally be desirable, of this arrangement is the avoidance of chromatic aberration.

The method I have most frequently used is shown in Fig. 1, in which A is the source, R a spherical reflector, C a condensing lens, and S the slit.

In this way two distinct images are formed on the slit, one an inverted image produced by the direct light, the other an erect image given by the reflected light; and evidently they may be superimposed. But since the reflected light shines back through its own source, it must necessarily suffer greater or less absorption, so that the resulting brilliancy of the superimposed images is less than the sum of those of the direct and reflected images separately. Nevertheless, the combination gives spectra distinctly more brilliant than those produced by the direct light alone, and therefore much of the reflected light must somehow get through the source, and does so probably because the lumi-

nous vapors are not sufficiently dense or extensive to form a practically continuous intercepting layer.

To demonstrate photographically the efficiency of the apparatus, I have taken advantage of the fact that silver is a poor reflector of ultra-violet light, but an excellent one of longer wave-lengths. The first three negatives shown in the plate were taken in the region of $\lambda 3200$ of the third order, which coincides with $\lambda 4800$ of the second order. The outer portions of I are due wholly to light reflected from a silver surface, while the middle strip was produced by light directly from the arc made to pass through a silver film, on a quartz disk of sufficient thickness to be nearly opaque to all luminous rays. The position of maximum transmission naturally coincides with that of minimum reflection, approximately $\lambda 3200$, and therefore the heavy lines on the outer portions of I belong to regions of longer wave-length.

The outer portions of II are also due to reflected light alone, but the middle strip was produced by undisturbed light directly from the arc. It will be noticed that, while the times of exposure were as nearly as possible the same and the source kept constant, the ultra-violet lines have very unequal intensities in the direct and reflected portions, and that those of longer wave-lengths differ but little from each other. Finally, the middle strip of III is due to direct light, while its outer portions were produced by the joint effect of the superimposed images, direct and reflected. The arc was practically constant and the times of exposure the same. Here it is seen that those ultra-violet lines which are scarcely at all reflected have nearly equal intensities in the outer and middle portions, while those of longer wave-lengths that are strongly reflected are much heavier in the outer parts. The conclusion, therefore, is that the vapors of the arc do not absorb all the reflected light, and that the method described does materially increase the brilliancy of arc-, and presumably of certain other spectra.

Incidentally it is seen that a silver reflector, or screen, can be used as an aid to differentiate between ultra-violet lines and those of longer wave-length.

In most of my work I have used silver-on-glass reflectors, but,

PLATE XIV.

VIII.

VII.

VI.

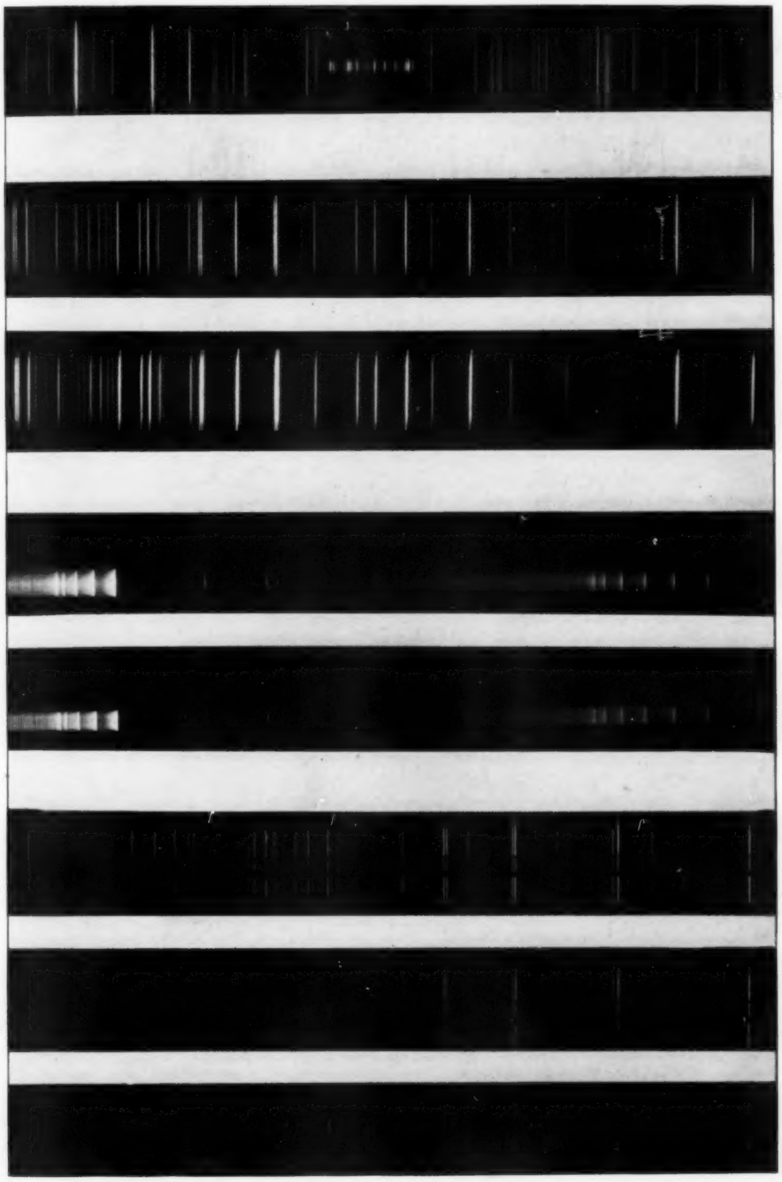
V.

IV.

III.

II.

I.



while this is the best known reflector of visible light, it is, as shown by the plate, a very bad one for the ultra-violet, and therefore for this region some other material should be used, probably magnalium for the best results.

d) Of the many possible optical trains that might be used to illuminate the slit, there is one, other than those above described, with which I have worked that, for small images, yields good results with the concave grating. This consists of a spherical condensing lens used in the ordinary way, either with or without a reflector behind the source, in conjunction with a double concave cylindric lens of short focal length, placed close to the slit and with its axis at right angles to the slit's direction.

By focusing the light on the slit with the condensing lens, and then introducing the cylindric lens as above described, the image will be elongated in the direction of the slit, while its width at the center will remain unaltered; and the pencil of light that gets through, instead of covering and surrounding the grating with a circle, will cover it with a surface roughly rectangular in shape, the length of which is equal to the diameter of the original circle, while its width is much less.

The cylindric lens does not appreciably alter the amount of light that gets through the slit, but places a much larger percentage of it on the ruled surface, so that the final effect is to lengthen out the spectrum lines, owing to the elongated image, and, on account of the astigmatism of the grating, to increase their brilliancy.

These effects are shown in negatives IV and V, the cylindric lens being used in the latter case. The source was a round hole, about one millimeter in diameter, in a sheet of metal placed close to a large, and therefore approximately uniform, electric arc. The times of exposure were as nearly as possible the same, and the plates were developed together and for the same length of time. Many eye observations were taken, and several other comparison plates secured in the first three orders of the spectrum, and the results were everywhere the same—a slight lengthening of the lines, and a marked increase in their brilliancy.

II. VIRTUAL INCREASE OF THE SLIT-LENGTH.

One of the peculiarities of the concave grating is its astigmatism, by virtue of which a point source in the slit produces a line image on the focal curve. When the slit is parallel to the rulings on the grating, the several line-images due to its consecutive points are superimposed, and a relatively intense line is the result. The longer the slit, within certain limits, the more intense the resulting lines, but when it is increased beyond a definite length, which depends on the grating and its position, the lines produced by light coming from one end of it fail to overlap those due to light from the other end, and clearly increasing the slit-length beyond this does no good. However, there are many sources of light, such as end-on Plücker tubes, sparks between close terminals, and others, whose images as produced by an ordinary condensing lens limit the slit to much less than its maximum efficient length. Besides, the image may always be rendered small by means of a short-focus condensing lens, and in many cases the only objection to this is the loss of some light due to greater chromatic aberration, and the increased difficulty of keeping the image properly placed on the slit.

In practically all cases, then, the circle of light that covers the grating may be, and usually is, much greater than the area of the ruled surface, and thus only a small portion of the light that gets through the slit is of any service.

Clearly, however, if this waste light could be made to fall on the ruled surface in the direction which it would have if it came from some point close to and in line with the slit, the astigmatism would cause the resulting spectrum lines to overlap those due to the direct light from the slit, and the brilliancy of the spectrum would be increased.

a) As already explained, excellent results of this kind can be obtained with a concave cylindrical lens placed before the slit, but similar effects are possible with suitable apparatus properly located between the slit and grating. One of these, which, owing to the difficulty of its construction, will probably have only a theoretical interest, is a curved convex cylindrical lens—a portion of a ring—of proper focal length, and of such shape and

position that it will be normally intersected by each plane determined by the slit and a line on the grating.

b) There is another method, however, efficient, simple to construct, and easy to use. This consists of a pair of optical flats close to the slit, but between it and the grating, with their ends properly separated and the pair so adjusted that the plane fixed by the slit and the central ruling on the grating shall be normal to their reflecting surfaces. Chromatic aberration is thus avoided.

The method is shown schematically in Fig. 2, which also gives a geometric means of determining the proper inclination of

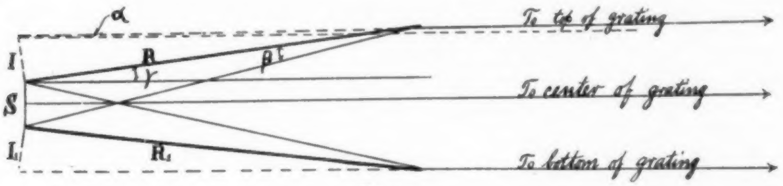


FIG. 2.

the reflectors to each other for any given slit-length and grating distance. For the sake of keeping the lines well separated in the drawing the angles are greatly exaggerated.

In the figure S is the slit, R, R_1 the two reflectors, and I, I_1 the slit's images in these reflectors. For a given position of the grating let a ray from the bottom of the slit be reflected from a point near the end of the upper reflector to the top of the grating. Other rays from the same point in the slit will go directly to the grating, others miss it entirely, but still others will be reflected from nearer points on R to parts of the grating below the top. The same thing holds for every other point in the slit, except that the higher it is, the nearer will be the parts of R that reflect its light to the grating. Similarly for the lower reflector.

To determine the proper setting of the reflectors, draw a line from the upper end of the image I, which should be of the same length as S, past the far end of R to the top of the grating, and another from the same point parallel to the line that joins the center of S with the middle point of the ruled surface. Let the

angle so formed be α, then if l is the length of the rulings on the grating, and L the distance from the slit to the grating,

$$\tan \alpha = \frac{l - 3S}{2L} \text{ nearly.}$$

Let the angle between R and the above ray to the top of the grating be β, and the length of the reflector a, then

$$\tan \beta = \frac{S}{a} \text{ nearly.}$$

Finally call the semi-angle between R and R_1 γ, then $\gamma = \alpha + \beta$, a determinate quantity.

The following table gives some of the numerical values of these constants with which I have worked.

Length of reflectors, 12.5 cm; focal length of grating, 6.4 m; length of rulings on the grating, 5 cm; distance of grating from the slit, a variable quantity, but as a somewhat extreme and unfavorable case say 4 m, which puts $\lambda 4400$, third order, at the center of the camera.

TABLE OF CONSTANTS.

Length of Slit	Distance Between Reflectors at Slit	Distance Between Reflectors at End from Slit	Required Radius of Circle of Light at Grating
1 mm	1 mm	4.47 mm	14 cm
1.5	1.5	5.92	17
2	2	7.38	22

From this it evidently is not necessary to use even a large condensing lens, or cone of light of wide angle; and, further, it clearly is easy to obtain a slit and its reflections practically three times the length of the slit alone, all sending light to the grating in such directions that it will produce superimposed, and therefore relatively brilliant, spectrum lines. Besides, the angle of incidence is so large that the images are nearly as bright as the slit itself. The reflectors with which I have worked consist of silver chemically deposited on glass optical flats, though this, in spite of the large angle of incidence, is probably not the best material for the ultra-violet.

In those cases where the image is practically a point and the

angle of the cone of light very large, better results might be obtained with suitable cylindrico-parabolic reflectors with their common foci at the center of the slit, but under all ordinary circumstances the flats are best and easiest to use.

I have found it convenient to fasten the reflectors respectively to an upper and a lower piece of brass, and to provide these with two sets of screws, one of which adjusts the reflectors relatively to each other, while the other, by resting on a small platform, adjusts the combination to the slit. The successful use of this attachment, instead of being difficult, as one might suppose, is very easy. None of the adjustments is difficult, and once the device is properly set, but little additional attention is required other than keeping the image at the proper place on the slit.

The general character of the results is shown in negatives VI and VII. Since these were taken only for the purpose of illustrating the principle, a very short slit, of about one millimeter, was used instead of a small image. It will be noticed that the lines of VI are triple, the outer components being broad and hazy; and that, if all three were made equally sharp and brought together, they would overlap through most of their length and produce a decidedly more intense line. This effect of tripling the lines and blurring the lateral ones was secured by tipping the mirrors, and thus putting the images out of line with the slit and also out of line with the rulings on the grating. Negative VII was taken when the mirrors were properly adjusted, and though the three sets of lines are here superimposed, it is free from noticeable defects of any kind.

III. SHAPE OF THE GRATING.

The general theory of reflecting gratings leaves great freedom of choice as to the shape of the surface, but the difficulties of construction, convenience of use, and other considerations so narrow the limits that, to the best of my knowledge, only flat and spherical concave surfaces are used.

If the light is sufficiently intense, the astigmatism of the concave grating as commonly mounted will do no harm, but in the case of feeble sources, or even faint lines in a bright source, this

will cause many parts of the spectrum to be overlooked that could easily be seen if all the energy was concentrated to closer limits. It would therefore be very desirable, while retaining normal spectra, to reduce the astigmatism to a minimum, and consequently it seems worth while to determine what surface will do this, and, if the theoretical one is difficult of construction, to find the nearest practical approach to it.

Let the slit, grating, and camera be, as in the Rowland mounting, on the vertices of a right-angled triangle, as shown in Fig. 3, where S is the slit, G the grating, and F the position of the camera or viewing telescope. Let the plane determined by $S\ G\ F$ be horizontal, and the slit, which should be parallel to the rulings on the grating, vertical. Let the surface of the grating, concave as viewed from F, be a portion of a torus, and let the rulings be at right angles to the equator, and be divided into equal upper and lower halves by it. Further, let the radius of horizontal curvature of the grating be equal to $G\,F$, and its radius of vertical curvature equal to any desired value. Also let the rulings be equally spaced along a horizontal chord, so that the grating as completed and mounted will differ from the usual spherical concave grating only in having a different radius of vertical curvature. With these conditions it will be found, on making somewhat tedious but simple enough substitutions in Runge's formulæ,[1] *i. e*, by using the equations of a torus instead of those of a sphere, that the two concave gratings, spherical and toroidal, scarcely differ except in the matter of astigmatism.

The problem then reduces to that of finding the vertical curvature of a grating whose horizontal curvature is given, that will produce the required amount of concentration.

Let this requirement be that a point in the slit shall give a point image. To do this evidently the vertical curvature must be such that the sum of the distances from the given place in the slit to any point on a fixed ruling, say the middle one, and from that same point to the focus shall be a constant; that is, this particular ruling must be on the surface of an ellipsoid of revolution whose foci are at S and F.

[1] KAYSER'S *Handbuch der Spectroscopie*, I, p. 452 ff.

Let $A\ G\ B\ C$ be the horizontal section of this ellipsoid. Then to determine the proper radius of vertical curvature of the torus, cut this ellipsoid by a vertical plane passing through F and G; that is, by a plane passing through one focus and the end of a latus-rectum through the other focus and normal to the plane determined by this latus-rectum and the major axis.

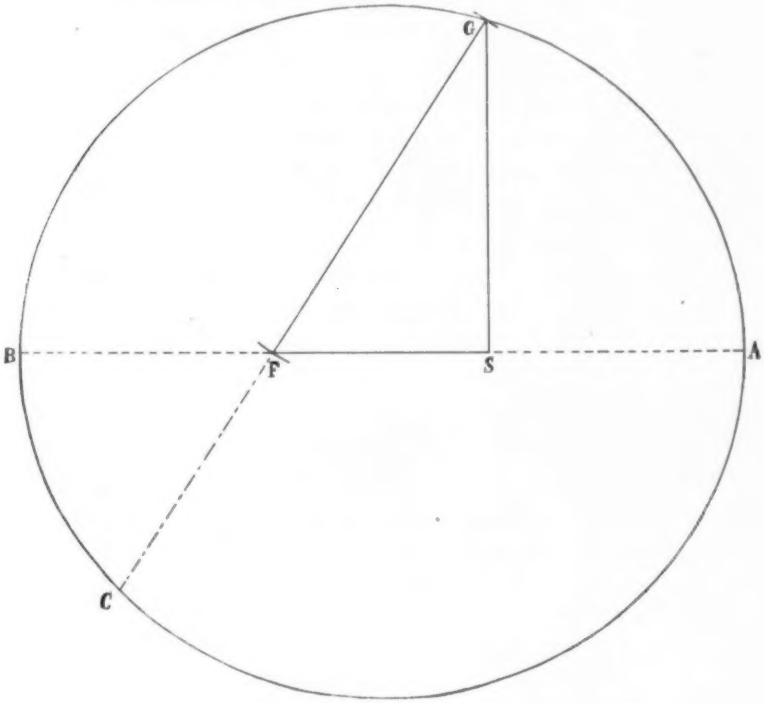


FIG. 3.

The curve thus cut out of the ellipsoid is an ellipse, and on revolving it about a vertical axis passing through F and parallel to its minor axis the required torus, a part of whose surface about G forms the grating, is generated.

Such an elliptical toroidal surface, however, is quite beyond the power of ordinary skill to form, but any uniform curve that closely fits this ellipse at the end of its major axis would give very nearly the same results, and doubtless among these the circle is the simplest; and, moreover, at the end of the major axis,

the place required, a circle whose radius is equal to the semi-latus-rectum has a very high order of contact with the ellipse, so that the circle is not only the simplest curve, but also one of closest approach to the ideally correct one.

To generate the required circular torus, revolve a circle whose radius is equal to the semi-latus-rectum of the elliptical section, as above described, at right angles to its plane, about a vertical axis passing through F, and have it so situated that the equator of the torus shall pass through G.

Of course, such a surface could give zero astigmatism at only one place, at F, where SF is the distance between the foci of the ellipsoid of revolution. It will thus be necessary, after determining the radius of horizontal curvature GF, and the ruling to be used, to decide in what part of which spectrum the maximum intensity is desired. This will fix the value of SF, and through it, as shown above, the radius of vertical curvature, which in all cases will be equal to SG.

This same value for the vertical curvature, with the condition that a point source at S shall give a point image at F, is readily obtained from Mitchell's[1] and also from Runge's[2] general equation for astigmatism, but possibly the above direct and simple discussion of the problem is not superfluous, since it shows that the figure, as determined by these equations, is only an approximation, though an exceedingly close one, to the ideally correct surface.

Mitchell's equation is

$$C = -Z + Z\sqrt{r\left(\frac{\cos\mu + \cos\gamma}{\rho} - \frac{1}{R}\right)},$$

in which C is the half-length of a spectrum line due to a point source in the slit, Z the half-length of a ruling, r the radius of horizontal curvature, R the distance of the slit from the grating, ρ the radius of vertical curvature as I use it, or radius of the sphere as Mitchell uses it, γ the angle of incidence, and μ the angle of diffraction.

[1] ASTROPHYSICAL JOURNAL, **8**, 107, 1898.

[2] KAYSER'S *Handbuch der Spectroscopie*, I, 464.

When the Rowland mounting is used, $R = r\cos\gamma$, and at the center of the camera $\mu = 0$; and therefore $C = 0$ when

$$r\left(\frac{1+\cos\gamma}{\rho} - \frac{1}{r\cos\gamma}\right) = 1\ ,$$

that is, when

$$\rho = r\cos\gamma = R.$$

Runge's expression for the entire length of a spectrum line is

$$\frac{r'}{r}s + \left[\rho - a' + \frac{r'}{r}(\rho - a)\right]\frac{l}{\rho}\ ,$$

where s = length of slit, l = length of ruling, ρ = radius of curvature, vertical as I use it, r = distance of slit to grating, r' = distance of camera from grating, a = the x co-ordinate of the slit when the center of the grating is taken as the origin, a' = the corresponding x co-ordinate of the spectrum line.

When the Rowland mounting is used, and the x axis is the line joining the grating with the camera, we have, where γ is the angle of incidence,

$$a' = r'\,,\ a = r\cos\gamma,\ \text{and}\ r'\cos\gamma = r;$$

and therefore in this case for point sources, that is with $s = 0$, the length of the spectrum lines becomes

$$\left(\rho - r' + \frac{r'}{r}\rho - r\right)\frac{l}{\rho}\ \ ;$$

and this vanishes when $\rho = r$.

Evidently, then, zero astigmatism may be obtained by having the radii of horizontal and vertical curvature of the grating equal respectively to its distances from the camera and the slit.

Finally, it would be extremely desirable so to set the cutting diamond point that the grating shall give its most brilliant spectrum at that place where the astigmatism is least.

Possibly a satisfactory approach to the above surface may lie beyond the skill of practical opticians, but, whether for the present this is true or not, it seemed to me worth while to discuss one of its valuable properties when used for a grating.

IV. CAMERA ATTACHMENTS.

Prism and plane-grating spectrographs, when illuminated by a line source, produce line images, while the spherical concave

grating, as usually mounted, gives lines, whether the source is also a line or only a point.

Therefore, in all these cases the energy in any given wave-length is spread out over a line of greater or less magnitude, and, if it happens to be very feeble, may not be detected at all. Clearly, then, it would be desirable to concentrate this energy within narrower limits, and for photographic purposes this is quite possible, since for a given wave-length the actinic effect depends rather on the quantity of light that reaches a given point than on small differences in direction.

In what follows I shall assume that the spectrum lines are straight, as they are when due to gratings, either plane or concave, and as they may be in prism instruments, provided the slit is properly shaped. Further, though the principles are exactly the same for all, I shall describe the methods as applied to a large concave grating spectrograph, the instrument with which I have worked.

a) One method of thus concentrating the spectrum lines is to place in front of the photographic plate a short-focus cylindric lens, whose axis is parallel to the focal curve. By suitably adjusting the distance between the plate and lens the normally long lines are reduced to very short ones, and the intensity greatly increased. This method, however, is open to several objections. The lines probably will not have exactly the same intervals between them that they would have without the lens, and, besides, they are not so clearly defined. If the lens is long, it must necessarily be made of glass, and therefore not be applicable to much of the ultra-violet. Still, even with all these objections, the cylindric lens is of service in hunting for very faint lines, especially if they happen to be somewhat hazy.

b) Another, and in most cases much better method is to place good reflectors in front of, but close to, the plate. This arrangement is shown in Fig. 4, where P is the photographic plate, R_1, R_2 the reflectors, and G the grating. Evidently some of the light will reach the plate directly, while two other portions will be reflected to the same place, one from R_1, the other from R_2, and the three acting together will correspondingly increase

the photographic effect. The reflected rays clearly pass over somewhat longer paths than do the direct ones, but this difference, one millimeter at most, is not enough, when long-focus gratings are used, materially to affect the definition.

To secure the best results the surfaces of the reflectors must be normal to a plane containing the spectrum line in question and passing through the center of the grating. Therefore, for the middle of the camera of a concave grating the reflectors should not be optical flats, but each should be a portion of a right cone whose vertex is on the tangent to the middle of the central ruling. For a short distance this very closely coincides

FIG. 4.

with a flat, and negative VIII was secured with such optical plates. A mere glance at this negative will show that the reflectors greatly increase the photographic effect, while a careful examination of it will reveal but little, if any, injury to the definition.

Much greater concentration could be had by using surfaces whose vertical sections through the axis give parabolas instead of straight lines as furnished by the cone. The photographic plate should, of course, in this case be placed near the latus-rectum. Each reflecting surface, according to this plan, would be part of a parabolic toroid.

Accurately to figure either of these surfaces, the conical or parabolic toroidal, would be difficult, but even for the best results accuracy of shape is not essential. It is only necessary that the reflected light should fall somewhere on a short straight line, and therefore it is sufficient if the horizontal sections of the reflectors are true circles. The vertical sections in the one case need not give perfectly straight lines, nor those of the other exact parabolas. With these conditions the surfaces would be very much more easily figured, and yet quite as efficient in every way.

Evidently in many cases two or more of these methods may be combined, with the result of correspondingly multiplying the final brilliancy of the spectrum lines.

While I have seen no reference to the actual use of any of these modifications or attachments, still from their very simplicity it would be surprising if no such application has been made of them. Indeed, Rowland[1] suggests the use of a cylindric lens, which from the context I take to be the same as IV, *a*, but does not say that he actually so used it. Besides, I know that I, *d*, has independently occurred to Wadsworth, but I have seen no account of its use in this way.

The material of the grating, various photographic processes, and manipulations, and even means of intensifying the brilliancy of the arc, flame, or other source, might all be discussed under the general title of this paper, but at present I have nothing to contribute on any of these important points.

UNIVERSITY OF VIRGINIA,
April 1903.

[1] *Physical Papers*, p. 489.

THE SPECTRUM OF *o CETI*.[1]

By Joel Stebbins.

On account of the great instrumental power required for the observation of the spectra of faint objects, changes in the spectra of long-period variable stars have not been well studied. In fact, there is no star which undergoes a large variation in brightness whose spectrum has been systematically followed from maximum to minimum, or *vice versa*. It is proposed to give here the results of a study of the spectrum of *o Ceti*, or *Mira*, made, at the suggestion of Director Campbell, with the thirty-six-inch refractor of the Lick Observatory, from June 1902 to January 1903. During this period the star faded in brightness from 3.8 to 9.0 magnitude. The first photograph of the spectrum was obtained about three weeks after the predicted time of maximum, and a series of plates was secured covering the interval to minimum. No negatives were obtained after the star had again begun to increase in brightness.

The most important articles concerning the spectrum of *Mira* are those of Vogel,[2] Sidgreaves,[3] and Campbell.[4] Neither Vogel nor Sidgreaves followed the star long enough to find much change in its spectrum, and Campbell's work was mainly in connection with observations of the star for radial velocity, with the Mills spectrograph.

INSTRUMENTS AND METHODS.

The spectrograph used in my observations was the one employed by Messrs. Campbell and Wright in their work on

[1] "Dissertation in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the University of California," *Lick Observatory Bulletin* No. 41.

[2] H. C. Vogel, "Ueber das Spectrum von *Mira Ceti*," *Sitzungsberichte der Berliner Acad.*, p. 143, 1896.

[3] Walter Sidgreaves, "The Spectrum of *o Ceti* as Photographed at Stonyhurst College Observatory," *Monthly Notices*, **58**, 344, April 1898.

[4] W. W. Campbell, "Note on the Spectrum of *o Ceti*," Astrophysical Journal, **9**, 31, January 1899.

Nova Persei,[1] designated as "Spectrograph I." It is the regular Mills spectrograph converted into a one-prism instrument. It gives good definition, on the same photograph, of the region from $\lambda 3700$ to $\lambda 5600$. The length of this range of spectrum is 28 mm. Although this dispersion is only about one-fifth of that of the three-prism instrument, it is enough to yield a very fair determination of velocity.

When the seeing is good, an exposure of ten minutes will give a satisfactory negative of a star to which the *Draper Catalogue* assigns the photographic magnitude 5.0. If *o Ceti* were of about the tenth photographic magnitude at minimum, it would require, roughly, an exposure of one hundred times as long as a fifth-magnitude star, or about sixteen hours. Some of the light being in bright lines, we should expect a still longer exposure to be necessary. This estimate agrees with my experience. About July 1, 1902, an hour's exposure, just before daylight, could be made on the star, and it was bright enough to photograph in that time. An exposure of six hours at the time of minimum, using the fastest photographic plate obtainable, was not sufficient to produce a measurable image, although much could be seen in a qualitative way. On January 5, 1903, the date of my last negative, an exposure of five hours, beginning soon after sunset, was possible. Early in March 1903, the spectrum was again bright enough to record itself with a fairly short exposure; and in the absence of the writer, Messrs. Reese and Curtis were ready to make an attempt, but bad weather prevailed.

A Huggins reflecting slit is used with this instrument. A ninth-magnitude star can be followed accurately.

No flexure of the instrument was noticed on any of the earlier plates. The comparison spectrum was inserted at least four times during each exposure, and the definition was satisfactory. Several long exposures in September and October were imperfect, but the trouble was finally removed by taking greater precautions in tightening the various clamps and screws.

As there were no means of controlling electrically the

[1] *L. O. Bulletin* No. 8.

temperature of the instrument, changes of temperature must have effected the definition. The spectrograph when in use was covered with two thicknesses of woolen blanket.

The same emulsion of Cramer's "Crown" plates was used for most of the work. A few exposures in July and August were made on Cramer's "Isochromatic Instantaneous," but the "Crown" plates were more sensitive.

TABLE I.

o Ceti. 13E, 1902, July 16. $\lambda = 2123.10 + \frac{332873}{220.653 - R}$.

Description	Micrometer R.	$R_0 - R$	$\frac{1}{R_0 - R}$ 0.00	λ From Formula	Correction to Formula	Reduction to Sun	λ
	20.706	199.947	500138	3787.91	*+0.14*		*3788.05*
	21.560	199.093	502278	3795.05	*+0.10*		*3795.15*
Bright, faint	21.950	198.703	503264	3798.33	+0.10	+0.36	3798.79
	26.124	194.529	514062	3834.27	*+0.09*		*3834.36*
Bright	26.301	194.352	514530	3835.83	+0.06	+0.36	3836.25
Bright, faint	28.241	192.412	519718	3853.10	+0.05	+0.37	3853.52
	29.012	191.641	521809	3860.06	*0.00*		*3860.06*
	32.111	188.542	530386	3888.61	*+0.06*		*3888.67*
Bright	32.208	188.445	530659	3889.52	+0.03	+0.37	3889.92
	32.870	187.783	532530	3895.75	*+0.05*		*3895.80*
	33.300	187.353	533752	3899.82	*+0.03*		*3899.85*
Bright, faint	33.950	186.703	535610	3906.00	+0.02	+0.37	3906.39
	36.230	184.423	542232	3928.04	*+0.04*		*3928.08*
	40.364	180.289	554665	3969.43	*−0.02*		*3969.41*
H. line of Sun	40.345	180.308	554607	3969.24	0.00	+0.38	3969.62
Bright	40.479	180.174	555019	3970.61	0.00	+0.38	3970.99
5 wide	41.381	179.272	557812	3979.91	−0.01	+0.38	3980.28
5 wide	41.665	178.988	558697	3982.85	−0.01	+0.38	3983.22
3	42.396	178.257	560988	3990.48	−0.01	+0.38	3990.85
Bright place	43.116	177.537	563263	3998.05	−0.01	+0.38	3998.42
4	43.251	177.402	563692	3999.48	−0.01	+0.38	3999.85
Bright place	43.518	177.135	564541	4002.30	−0.01	+0.38	4002.67
	43.810	176.843	565473	4005.41	*0.00*		*4005.41*
Bright place	43.996	176.657	566069	4007.39	−0.02	+0.38	4007.75
4 wide	44.170	176.483	566627	4009.25	−0.02	+0.38	4009.61
4	45.282	175.371	570220	4021.21	−0.02	+0.38	4021.57
5 very wide	45.610	175.043	571288	4024.76	−0.02	+0.38	4025.12
4	45.850	174.803	572073	4027.38	−0.03	+0.38	4027.73
4 fine	46.436	174.217	573997	4033.78	−0.03	+0.38	4034.13
	47.546	173.107	577677	4046.03	*−0.05*		*4045.98*
3	48.394	172.259	580521	4055.50	−0.03	+0.39	4055.86
	49.130	171.523	583012	4063.79	*+0.15*		*4063.94*
	49.849	170.804	585466	4071.96	*−0.05*		*4071.91*
4 wide	50.414	170.239	587409	4078.43	−0.04	+0.39	4078.78
3 poor	50.850	169.803	688918	4083.45	−0.04	+0.39	4083.80
3 poor	51.274	169.379	590392	4088.36	−0.04	+0.39	4088.71

All of the plates taken in this work were measured and reduced with the iron spark-spectrum as comparison. From the ultra-violet to $\lambda 4415$ there are many strong and sharp iron lines. From $\lambda 4415$ to $\lambda 5600$ the iron lines are fainter, and many of them have companions. The region from $\lambda 4800$ to $\lambda 5600$ of the iron spectrum was photographed with three prisms. It was found that there were several lines in this region which had no companions, and which could be used without hesitation. Close double lines were assumed to have positions depending upon the relative intensities of their components.

The plates were measured with one of the measuring microscopes in use for the regular line of sight work. Each plate was measured with both violet left and violet right in the eyepiece.

A plate of the sky was taken with a very long slit and the amount of the curvature of the comparison lines was determined in the same manner as by Campbell.[1] The curvature corrections were found to be insignificant.

The reductions from micrometer readings to wave-lengths were based on the Cornu-Hartmann formula, much of the computation being done with a Brunsviga calculating machine. The wave-lengths of the comparison lines were taken from Rowland's table. The example on page 343 shows the complete reduction of a plate after the constants of the formula had been derived. Italicized figures are used for the comparison lines.

DATA OF THE OBSERVATIONS.

In Table II is given a list of the plates secured with Spectrograph I. Mr. Wright obtained three plates in 1901, and he kindly turned them over to me for measurement and discussion. The width of the slit is expressed in terms of the divisions on the head of the screw, one division corresponding to 0.025mm. One plate, taken on September 16, was discarded on account of great flexure during the exposure. Something of interest was found on all other plates, except 57 A.

The brightness of the star at the time when each plate was

[1] ASTROPHYSICAL JOURNAL, 8, 144, 1898.

taken is shown in Fig. 1. The observations of visual magnitude are given at the end of this paper. As the plates are well distributed along the light curve until about the time of the minimum, no great change in the spectrum could have escaped observation.

ABSORPTION SPECTRUM.

As is well known, *o Ceti* and the other long-period variables have absorption spectra of Secchi's third type. Some observers have found the region from $H\gamma$ towards the red crossed by a series of dark bands, with edges sharp towards the violet, and they report that from $H\gamma$ to the ultra-violet the dark-line spectrum is very similar to that of the Sun. At first glance this seems to be verified by my plates, but a closer study shows the details to be very different. Fig. 2 shows an eightfold enlargement of the solar spectrum, photographed with Spectrograph I on a lantern-slide plate. The absorption spectrum of the star, Figs. 3–6, is seen to resemble little that of the Sun. The date of Fig. 4 should be August 11, instead of August 4, as is printed.

In comparing the star spectrum with the solar spectrum, it was not found best simply to measure the plates and then look for coincidences in Rowland's table. It is easy to find a line in the table which agrees in position with the one on the plate, but the intensities may be very different. The method adopted was to compare a plate of *o Ceti* with one of the sky. The two negatives, film sides together, were examined under the microscope with a low power.

The strong calcium lines *g*, H, and K, are present in the spectrum of the star, the *g* line being much more intense than in the solar spectrum. The strong iron lines of the Sun are not so prominent in *o Ceti*; in fact, they do not show with low dispersion. Of the large number of lines in the star spectrum, there are very few which coincide with lines of like intensity in the solar spectrum.

The absorption spectrum of *Mira* was measured accurately on seven plates. Each plate was measured and reduced independently, so that a faint line might be measured on one plate without

being noticed on any of the others. This does not mean that it had developed, or that its intensity had changed. Such lines, of which many were measured, could be easily obscured by an irregular arrangement of the silver grains. The best method of verifying changes is to examine different plates simultaneously, in pairs, under the microscope. This has been done, and all changes in intensity or character have been noted.

TABLE II.

Plates Secured With Spectrograph I.

Plate No.	Astronomical Date	Mt. Hamilton Sidereal Time, Middle of Exposure	Length of Exposure	Brightness of *o Ceti*, Mag.	Photo-Plate	Slit Width	Seeing	Remarks
	1902							
2B	June 27	22h 09m	0h 45m	3.8	Crown	1.4	Poor	
3C	27	22 39	0 10	3.8	Crown	1.4	Poor	
4E	27	22 46	0 03	3.8	Crown	1.4	Poor	
7C	July 6	22 47	1 15	4.1	Crown	1.4	Good	
8D	6	23 28	0 05	4.1	Crown	1.4	Good	
9E	6	23 35	0 02	4.1	Crown	1.0	Good	
13E	16	23 07	2 00	4.6	Iso.	1.4	Fair	
14F	16	0 12	0 05	4.6	Iso.	1.0	Fair	Shows bright lines only
18F	22	23 22	2 30	5.1	Iso.	1.4	Fair	
21F	29	23 30	2 40	5.3	Iso.	1.4	Fair	
25F	Aug. 4	0 07	3 00	5.4	Iso.	1.4	Good	
26D	4	1 44	0 07	5.4	Crown	1.0	Good	Shows bright lines only
27D	11	0 58	2 35	5.6	Crown	1.5	Fair	
28D	25	0 53	2 35	6.4	Crown	1.5	Poor	
33D	Sept. 6	0 45	3 00	7.0	Crown	1.5	Poor	
39D	22	2 20	4 40	7.1	Crown	1.6	Poor	Flexure during the exposure
42A	Oct. 4	1 47	5 53	7.8	Crown	1.8	Fair	Slight flexure
48A	26	4 10	5 40	8.5	Crown	1.8	Fair	Flexure
54A	Nov. 25	3 10	5 00	9.2	Crown	2.5	Poor	
57A	Dec. 21	3 18	5 25	9.0	Crown	3.0	Poor	Nothing found on this plate
	1903							
58A	Jan. 2	3 12	5 17	9.0	Crown	3.0	Poor	
59A	5	3 36	4 51	9.0	Crown	2.5	Fair	
	1901							
2211C	Aug. 3	1 15	0 20	...	Iso.	1.2	Good	
2212D	3	1 32	0 03	...	Iso.	1.2	Good	Bright lines only
2235D	17	1 26	1 20	...	Iso.	1.3	.....	

In Table III are given the wave-lengths of the absorption spectrum as derived from all the measures. The numbers expressing the intensity indicate, in a general way, the relative strength of the lines. It was intended, on each plate, to assign intensity 1 to the faintest lines distinguishable, and intensity 10 to the strong line at λ 4255. On this scale the *g*, H, and K lines might be 100 or 500, it matters little. The intensities assigned are merely relative, and no doubt the scale varies much in different parts of the spectrum. The lines on each plate were

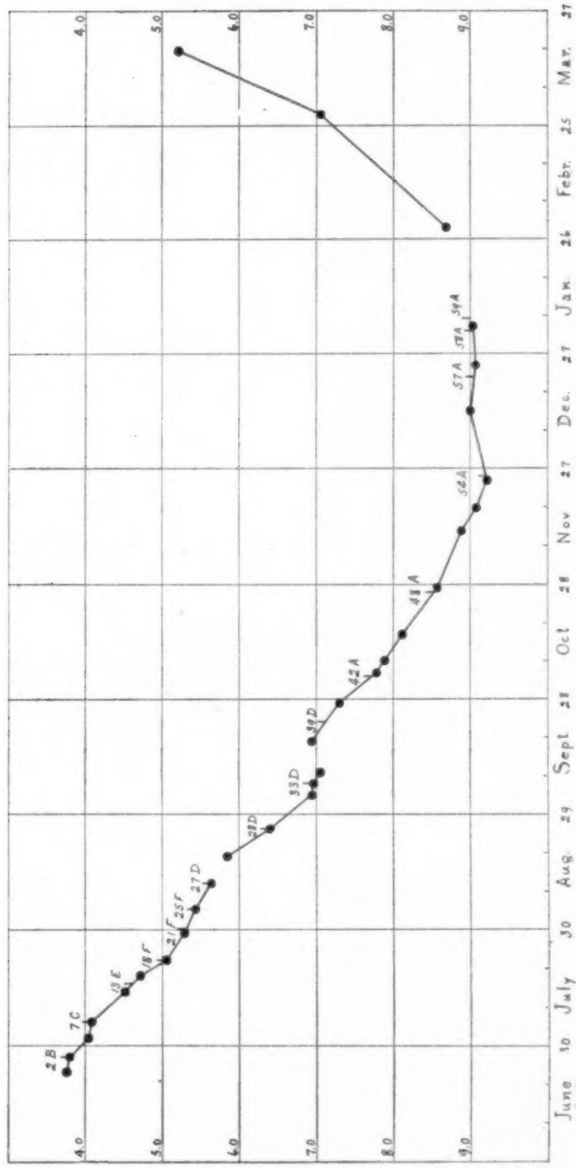


FIG. 1.—*o Ceti.* Light-Curve, 1902–3.

TABLE III.

Absorption Spectrum of *o Ceti.*

Intensity	Observed λ	Residuals in 0.01 t.m.							Remarks
		7C	13E	18F	25F	27D	28D	2235D	
	3936.—	..	..	..	..	—	—	..	K line of Sun, very strong. Adjacent bright lines interfere with measurement of λ
5 wide	3945.09	04	..	..	..	*01*	*02*	..	
5 wide	3949.28	14	..	..	..	—	*14*	..	
2 fine	3951.65	..	..	..	..	..	—	..	
2	3957.27	..	..	..	..	..	—	..	
4	3958.98	—	..	..	..	*03*	03	..	
5 wide	3962.55	—	..	..	..	00	00	..	
	3969.6–	—	—	..	..	..	—	..	H line of Sun, very strong. Adjacent bright lines interfere with measurement of λ
4 wide	3980.20	..	08	..	..	..	*09*	..	
5 wide	3983.18	10	04	..	*19*	*01*	05	..	
5	3990.64	..	21	..	*24*	*04*	07	..	
2 fine	3997.61	—	..	..	..	..	..	..	
4	3999.72	09	13	..	*02*	*07*	*22*	11	
4 wide	4005.6–	..	..	..	—	..	..	..	Perhaps several
5 wide	4009.63	..	*02*	..	05	17	..	*20*	Perhaps several
4	4010.04	..	..	..	..	..	—	..	
3	4012.18	..	..	..	*15*	..	23	*09*	
1	4018.91	..	..	..	..	..	—	..	
4 wide	4021.41	*14*	16	..	00	*08*	10	*04*	
5 wide	4025.08	17	04	..	*17*	08	03	*14*	
3 wide	4027.68	20	05	..	10	..	*09*	*26*	
2 wide	4030.16	..	..	..	03	..	*04*	..	
6	4032.22	*19*	..	..	15	*05*	38	*27*	
7	4034.04	05	09	..	*01*	*02*	03	*11*	
1 fine	4035.71	..	..	..	—	..	..	..	
2	4036.22	..	..	..	..	..	—	..	
3	4045.16	..	..	..	*03*	02	..	..	
2 fine	4047.02	—	..	..	..	..	..	..	
	4043.—	..	..	..	—	—	..	—	Several lines run together
	4050.—	..	..	..	—	—	..	—	
3	4053.25	..	..	..	..	..	..	—	
6	4055.71	..	15	..	*01*	*09*	*19*	12	
2	4058.14	..	.	..	12	..	..	*11*	
2 wide	4060.43	..	..	..	03	..	..	*03*	
	4064.—	..	..	..	..	—	—	..	Too wide and faint to measure. Probably several
4 wide	4068.24	..	..	..	..	..	..	—	
	4072.—	..	..	..	..	—	—	..	Too wide and faint to measure. Probably several
5 wide	4072.28	..	..	..	09	*01*	..	*09*	
2 fine	4077.24	—	—	..	08	*11*	02	—	On plates 7C, 13E and 2235D these two lines run together
7 wide	4079.51	—	—	..	*02*	04	*03*	—	
4 wide	4083.85	*15*	*05*	..	12	*36*	06	39	
3	4088.88	20	*17*	..	*07*	11	*04*	*05*	
1 fine	4091.33	..	—	..	..	..	..	..	
5	4093.55	..	18	..	00	*12*	*21*	13	
3	4097.08	..	..	..	01	13	*08*	*04*	
3 fine	4100.56	..	..	..	..	..	—	..	
4	4105.88	..	..	..	*07*	..	..	08	
5	4110.34	..	*07*	..	*09*	..	08	09	
5	4112.97	..	*07*	..	07	..	..	..	
4 fine	4116.14	..	..	..	..	..	..	—	
4 fine	4117.71	..	00	..	*15*	..	18	*01*	
	4117.9–	..	..	..	..	..	—	..	Several
	4119.1–	..	..	..	..	..	—	..	

TABLE III.— *Continued.*

Absorption of Spectrum of *o Ceti.*

Intensity	Observed λ	Residuals in 0.01 t.m.							Remarks
		7C	13E	18F	25F	27D	28D	2235D	
4 fine	4121.44	..	..	..	..	..	..	—	
4 fine	4122.62	..	..	..	..	..	..	—	
6	4124.66	01	21	..	*15*	..	*02*	*06*	
2 fine	4126.99	..	..	..	..	..	—	..	
3	4129.04	..	..	..	—	..	..	..	
3	4130.60	..	..	..	*04*	05	..	..	
4 fine	4133.00	..	..	..	..	.	—	..	
5	4135.32	*17*	05	..	*12*	*10*	17	15	
3	4137.77	11	..	..	..	..	..	*11*	
2	4140.96	..	..	..	00	..	..	*01*	
4 wide	4144.—	—	..	..	—	—	..	—	
3	4150.73	..	..	..	*12*	..	..	12	
3	4153.40	..	*04*	..	*01*	..	..	04	
3	4156.78	..	12	..	..	..	..	*11*	
4	4160.89	..	..	..	..	..	..	—	
3	4165.82	..	..	..	..	..	..	—	Poor
3	4169.27	..	..	..	17	..	00	*18*	
3	4173.56	..	—	..	..	..	..	..	
7	4175.41	11	28	..	*01*	03	*23*	*05*	
4	4178.32	*10*	13	..	*07*	*16*	23	*04*	
2	4180.96	..	..	..	..	*08*	07	..	
3	4183.73	..	..	..	—	..	..	..	
4 wide	4188.17	..	..	..	*16*	14	*23*	26	
5 wide	4191.79	*01*	08	..	07	*08*	*36*	32	
3	4199.79	..	..	..	..	..	..	—	
2 wide	4211.19	..	..	..	*27*	27	..	..	Poor
4 wide	4214.86	..	..	..	12	..	*11*	..	
	4227.84	00	28	..	—	*10*	*18*	—	*g* line of Sun, very strong
5	4235.37	..	*10*	..	04	..	07	..	
3	4242.82	..	..	..	*03*	..	..	04	
3	4251.60	..	02	..	*11*	..	..	10	
10	4255.46	06	33	..	*08*	*26*	*06*	01	
1	4259.64	..	..	..	—	..	..	..	
1 wide	4261.87	..	..	..	—	..	..	..	Poor
4	4273.15	..	*02*	..	00	..	..	02	
8	4275.84	00	17	..	*06*	*03*	*04*	*06*	
5	4285.28	..	—	..	..	..	..	.	
6	4290.72	*22*	..	..	13	03	*11*	17	
2 fine	4292.45	—	..	..	..	..	..	..	
1	4295.07	..	..	..	..	..	..	—	
2 fine	4297.56	..	..	..	..	..	..	—	
3	4300.16	06	..	..	..	..	..	*06*	
2	4304.06	..	—	..	..	..	..	..	
3	4307.23	*02*	*12*	..	..	..	..	15	
3	4310.57	..	07	..	..	..	..	*06*	
	4314.29	..	..	00	00	..	01	00	Head
2 fine	4320.03	—	..	..	..	..	..	..	
3	4326.97	06	..	..	*10*	..	..	05	
2	4331.13	..	..	..	—	..	..	..	
2	4348.12	..	..	..	—	..	..	..	
	4353.60	..	18	08	*06*	—	—	*78*	Head
4	4380.31	*03*	..	..	*06*	..	*25*	35	
5	4385.49	*12*	*09*	..	*04*	14	09	02	
4	4390.71	22	02	..	*14*	*11*	25	24	
	4395.89	24	..	24	*13*	—	—	*36*	Head

TABLE III.—*Continued.*

Absorption of Spectrum of *o Ceti.*

Intensity	Observed λ	Residuals in o.1 t.m.							Remarks
		7C	13E	18F	25F	27D	28D	2235D	
	4422.4	..	*2*	1	*1*	1	0	1	Head
4	4461.1	..	..	..	—	..	..	..	
	4463.0	..	*4*	*1*	*2*	3	4	0	Head
	4505.7	..	0	*1*	2	..	..	*1*	Head
4 wide	4514.7	..	..	..	..	—	..	..	
3 wide	4519.8	..	..	..	..	—	..	..	
2	4530.7	..	..	..	—	..	..	..	
4	4536.8	..	*2*	*3*	*1*	..	5	..	
	4548.8	..	*4*	2	*4*	..	..	6	Head
	4585.0	..	*2*	1	*3*	4	3	*3*	Head
	4626.8	..	*1*	*4*	*2*	6	2	0	Head
	4669.6	..	*1*	*3*	*5*	3	[21]	6	Head. Measure of Plate 28D
5	4709.2	..	2	0	..	1	..	*3*	rejected for discordance
	4714.2	..	*4*	3	1	..	..	..	Head
10	4739.5	..	1	2	*3*	1	3	*4*	
	4760.0	..	*2*	4	3	*4*	6	*5*	Head
	4804.2	..	0	*4*	*3*	0	5	1	Head
	4842.8	..	..	..	..	2	*2*	..	Head
	4954.1	..	2	*3*	*3*	4	0	0	Head
	5167.0	..	2	*8*	2	..	..	5	Head
	5308.3	..	—	..	..	..	..	..	Head
	5358.8	..	—	..	..	..	..	..	Head
	5439.4	..	—	..	..	..	..	..	Head
	5447.9	..	2	0	7	..	..	5	Head
	5498.0	..	—	..	..	..	..	..	Head
	5568.7	..	..	..	..	..	..	—	Head

assigned intensities when the plate was measured; and when the different results were brought together, a sort of mean of the estimates was taken for each line. Where the estimates did not agree well, the line was compared directly on two or more plates to see if any change had taken place.

The residuals in the table were formed by subtracting the mean wave-lengths from the values given by each plate. All plates were assigned equal weight in forming the means. Periods (. . . .) signify that when the plate was measured nothing was noticed in the spectrum at that place. A dash (—) denotes that the line was observed, but could not be measured accurately. When a line was measured on only one plate there is no residual, and the dash indicates the plate referred to.

Plate 18F was measured only from λ 4300 towards the red.

The comparison on 7 C being underexposed to the red of λ 4415, the plate was not measured in that region.

From the residuals in Table III it is found that the probable error of the wave-length of a dark line derived from one plate is ± 0.10 tenth-meter. When a line was measured on six plates, the probable error of its mean position is therefore ± 0.04 t.m. In computing the probable error, the residuals from all lines to the violet of λ 4400 were used.

Many of the lines being broad or unsymmetrical and difficult to measure, the residuals from different plates are not larger than would be expected. While the agreement of the results with each other is not a test as to systematic errors, yet I feel sure that the wave-lengths of but few of the dark lines measured on several plates can be in error by as much as 0.2 t.m.

A glance at the residuals shows that there is no evidence of variable velocity in the line of sight. Those from Mr. Wright's plate No. 2235 D, which was taken in 1891, indicate that the velocity was about the same during the corresponding phase of the star's light curve, a year previous. The residuals for each plate have been averaged; and if there were any change in the velocity it would appear in the mean residuals. The arithmetical means of the residuals to the violet of λ 4400, and the corresponding velocities in kilometers per second, are as follows:

TABLE IV.

Date	Plate No.	t.m.	km
1902, July 6	7 C	+0.02	+1
16	13 E	+0.06	+4
Aug. 4	25 F	−0.03	−2
11	27 D	−0.02	−1
25	28 D	−0.03	−2
1901, Aug. 17	2235 D	+0.02	+1

Since many of the lines were not measured on all of these plates, the average residual of one plate is not strictly the average deviation of the measures on that plate from the mean of all the plates, but no sensible error is introduced by this assumption. When it is remembered that all lines, good and poor, were

included in the means, and that these plates were taken with a one-prism instrument giving a dispersion of but one-fifth of that of the regular Mills spectrograph, the range of only 6 km on six plates is very satisfactory. None of the plates taken later in 1902 are good enough to afford comparable conclusions as to the velocity; and it was thought best to measure only first-class plates in this connection.

The result that the star's velocity was constant over a certain period was derived without assuming the coincidence of any of the star lines with lines of the solar spectrum, or with other known lines. A determination of the actual radial velocity requires an assumption as to what the wave-lengths of the star lines would be if they were not affected by velocity. Agreements of star and solar lines were looked for, by direct comparison of the star plates with a solar plate, and the only coincidences which seem certain are given in Table V. The wave-lengths and other data of the solar lines are from Rowland's table.

The H and K lines could not be measured accurately; the double manganese line at λ4030.92 gives a discordant result, which was rejected, and it looks as though both a strontium and a titanium line make up a stellar line at λ4079.51. The velocity of +66 km was therefore derived from measures of only six lines, and none of these are fine and sharp enough to give the best determination.

TABLE V.

Coincidences of Dark Lines in the Spectra of *o Ceti* and the Sun.

o Ceti		Sun λ	Displacement t.m.	Velocity. km	Sun Substance and Intensity
Intensity and Character	λ				
Strong	3936.—	33.82	———	———	*Ca* 1000 (K)
5 wide	3945.09	44.16	+0.93	+71	*Al* 15
5 wide	3962.55	61.67	+0.88	+67	*Al* 20
Strong	3969.6–	68.62	———	———	*Ca* 700 (H)
6	4032.22	30.92	[+1.30]	[+96]	*Mn* 4 and 5
7	4034.04	33.22	+0.82	+61	*Fe-Mn* 7
7 wide	4079.51	77.88	———	———	*Sr* 8
		78.63	———	———	*Ti* 3
Strong	4227.84	26.90	+0.94	+67	*Ca* 20 (*g*)
10	4255.46	54.50	+0.96	+68	*Cr* 8
8	4275.84	74.96	+0.88	+62	*Cr* 7
				Mean +66 km	

Campbell in 1898 found +62 km with the three-prism instrument. The interval between August 29, 1898, the date of his first plate that year, and August 25, 1902, is equal to 130 days more than four periods of 331 days. The radial velocity has therefore been observed to be constant over about two-fifths of the period of light change.

To determine more coincidences, I have measured one of the high-dispersion plates of *o Ceti*, taken by Dr. Campbell in 1897. Although the plate is underexposed, about seventy lines were measured between λ4300 and λ4420, and more than twenty coincidences were found by direct comparison with a solar plate. The results are given in Table VI. As was done for the one-prism plates, the intensities are expressed on an arbitrary scale of 10.

TABLE VI.

Absorption Spectrum of *o Ceti*. High Dispersion. Plate 576 B. December 15, 1897.

o Ceti		Sun λ	Displacement t.m.	Velocity km	Remarks
Intensity and Character	λ				
Several	4299.7–	.....	......	......	Narrower in ⊙
	4300.8–	.....	......	......	
3	4301.58	.....	......	......	Closer double in ⊙
3	4302.17	.....	......	......	
2	4303.56	02.69	+0.87	+60.6	*Ca* 4
5, double?	4307.10	.....	......	......	Not ⊙
3	4308.16	.....	......	......	Not ⊙
4	4308.94	——	——	——	07.91 *Ca* 3, 08.08 *Fe* 6
4	4310.83	.....	......	......	Not ⊙
1	4312.90	.....	......	......	Not ⊙
Several	4315.2–	.....	......	......	Not ⊙
	4316.1–	.....	......	......	
2	4319.77	18.82	+0.95	+65.9	*Ca, Mn?* 4
Bright place	4325.93	.....	......	......	Same in ⊙
6	4326.85	25.94	+0.91	+63.0	*Fe* 8
1	4327.96	.....	......	......	Not ⊙
1	4328.69	... .	......	......	Not ⊙
1	4329.53	.....	......	......	Not ⊙
1	4330.30	.....	......	......	Not ⊙
5	4331.13	30.19	+0.94	+65.0	*V* 0 Stronger than in ⊙
5	4333.92	32.99	+0.93	+64.4	*V* 0
Several	4334.68	.....	......	......	Not ⊙
	4335.29	.....	......	......	
Poor 2	4335.91	.....	......	......	Possibly weak lines in ⊙
1	4336.38	.....	......	......	
1	4337.07	.....	......	......	Not ⊙
2	4338.16	37.22	+0.94	+65.0	*Fe* 5

TABLE VI.—*Continued.*

o Ceti Intensity and Character	*o Ceti* λ	Sun λ	Displacement t.m.	Velocity km	Remarks
2	4338.61	37.72	+0.89	+61.5	*Cr* 3
1	4339.11	.....	......	......	Not ⊙
3	4345.56	44.67	+0.89	+61.4	*Cr* 4
4	4348.27	.....	......	......	Not ⊙
1	4352.16	51.22	+0.94	+64.8	*Cr* 3
Poor 2	4352.90	51.93	+0.97	+66.8	*Cr* 3
Head of band	4353.7-	.....	......	......	Not ⊙. Mean of 4 plates with one prism 4353.6
5	4353.91	52.91	[+1.00]	[+68.9]	*Fe* 4. This line always gives + residual in other stars
3	4356.97	.....	......	......	Perhaps ⊙, not certain
1	4349.70	.....	......	......	All weak lines in star No coincidences certain
1	4360.12	.....	......	......	
1	4360.65	.....	......	......	
1	4361.73	.....	......	......	
Poor 1 wide	4363.05	.....	......	......	
2	4365.56	.....	......	......	
2	4367.10	.....	......	......	
1	4367.87	.....	......	......	
4	4369.07	.....	......	......	Not ⊙
1	4370.48	.....	......	......	Not ⊙
1	4371.23	.....	......	......	Not ⊙
4	4372.22	——	——	——	(71.14 *Zr* 1, 71.22 —1, 71.44 *Cr* 4) same appearance
1	4373.17	.....	......	......	Not ⊙
Several to violet of	4376.4-	.....	......	......	Different in ⊙
Bright place	4376.68	.....	......	......	Not ⊙. This develops into a bright line
5	4377.06	76.11	+0.95	+65.1	*Fe* 6
1 wide	4378.06	.....	......	......	Different in ⊙
1 wide	4379.17	.....	......	......	
10	4380.27	79.40	+0.87	+59.5	*V* 4
1	4383.67	.....	......	......	Not ⊙
6	4384.62	83.72	+0.90	+61.6	*Fe* 15
7 double?	4385.90	——	——	——	84.87 *V* 3, 85.14 *Cr* 2
5	4390.26	89.41	+0.85	+58.1	*Fe* 2 Stronger in star than in ⊙
4	4391.06	90.15	+0.91	+62.2	*V* 2
Poor 2 wide	4392.76	91.92	+0.84	+57.4	*Cr* 1
7	4396.20	——	——	——	95.20 *Ti* 3, 95.41 *V* 2
2	4401.61	00.74	+0.87	+59.2	*V* 1
10 wide	4405.89	04.93	+0.96	+65.3	*Fe* 10
2	4407.02	.....	......	......	Not ⊙
4	4407.72	06.81	+0.91	+61.9	*V* 2
4	4408.70	——	——	——	07.81 V 2, 07.87 *Fe* 4
10	4409.41	——	——	——	08.36 *V* 2, 08.58 *Fe* 3, 08.68 *V* 2
Several to violet of	4416.7-	.....	......	......	Different in ⊙
4	4417.59	16.64	+0.95	+64.4	*V* 0. Stronger in star than in ⊙
Head of band	4422.5-	.....	......	......	Not ⊙. Mean of 6 plates with 1 prism, 4422.4
	Mean of 20 lines +62.7 km				

A comparison of Table VI with the corresponding part of Table III is a test of the reliability of the results obtained with one prism.

TABLE VII.

One Prism		Three Prisms	
Description	λ	λ	Description
3	4300.16	99.7– 00.8–	Several
2	4304.06	.....	Not measured
3	4307.23	07.10	5
3	4310.57	10.83	4
Head	4314.29	.....	Not measured
2	4320.03	19.77	2
3	4326.97	26.85	6
2	4331.13	31.13	5
2	4348.12	48.27	4
Head	4353.6–	53.7–	Head
4	4380.31	80.27	10
5	4385.49	84.62	6
		85.90	7
4	4390.71	90.26	5
		91.06	4
Head	4395.89	.....	Not measured
Head	4422.4–	22.5–	Head

As might have been expected, many lines observed as single with one prism are really made up of two or more components. This comparison also shows that the wave-lengths of Table III are probably not quite so accurate as the residuals indicate.

A brief summary of the number of dark lines of different elements observed in the spectrum may be of interest.

TABLE VIII.

Element	No. of Lines
Ca	6
Fe	11
Cr	9
V	11
Al	2
Sr	1
Mn	3 } ?
Ti	2 } ?

There can be no doubt of the presence of the first four elements in the list, and the aluminum and strontium lines are

prominent; but manganese and titanium must be considered as doubtful.

On account of the varying instrumental conditions it is easy to fall into error in judging as to changes in the intensity and character of dark lines. If all the negatives were of the same density and of uniform excellence, it would be easy to note such changes. There is one dark line which showed changes of which the reality is certain. This is the *g* calcium line at $\lambda 4227.84$. Figs. 3–5 show how it broadened as the star grew faint. Measures of its width are necessarily rough, and must depend much upon the judgment of the observer. The measures of two plates are as follows:

TABLE IX.

Date	Plate	Width
1902, June 27	2 B	2 t.m.
September 6	33 D	9 t.m.

Other plates taken between these dates gave intermediate values. The intensity of continuous spectrum, in the neighborhood of $\lambda 4227$, is almost the same on Plates 2 B and 33 D.

The general impression formed from examining the series of plates is that many other lines also grew broader as the brightness declined, but this is not certain. The effects of greater width of the slit, reduced intensity of the resulting negative, and flexure and temperature changes resulting from longer exposure, would all tend to make the lines wider and less sharply defined. The H and K lines are not shown on most of the plates, and nothing can be said as to changes in their character.

A few lines not visible on the early plates became prominent later. Four such lines have the following positions:

$\lambda 3990.64$	$\lambda 4093.55$
4045.16	4097.08

Lines of the solar spectrum which certainly coincide with these have not been found. The residuals in Table III indicate when these lines first appeared.

BANDS.

The prominent bands in the spectrum of *Mira* have been considered by some observers as a series of dark bands, with sharp edges towards the violet, and shading off toward the red. Others think them to be bright flutings like those of the arc spectrum of carbon. For convenience, they will be considered, in this paper, as dark absorption bands. On the plates of *o Ceti* and other third-type stars taken with Spectrograph I the bright portions of the banded spectrum are certainly brighter relative to the region above $H\gamma$, where there are no bands, than are the corresponding portions of the spectrum of a solar-type star. However, the dark portions are fainter than the same places in the solar type of spectrum.

In measuring the plates the micrometer wire was set on the division between a dark and a bright portion of the spectrum, so that the measurements remain the same whether the bands be considered as bright or dark. While the line of separation is probably sharp in most cases, its exact position is not easy to determine. No doubt the effect of irradiation plays an important part in direct visual observations. Since the bands considered as bright have their sharp edges towards the red, the effect of irradiation would be to make the observed wave-lengths of the heads too large. Corresponding to this visual error is the effect of spreading of the image on a photographic plate, causing an error in the same direction, and a slight allowance was made for it in executing the measures. At my request, Dr. Reese made several settings on the head of a band. The difference between his measures and mine was 0.3 t.m., my estimate being that much farther to the red. Although this was the only comparison made with another observer, it seems highly improbable that two persons should disagree by as much as one tenth-meter in the measurement of a sharply defined head.

No attempt was made to determine the position of the more diffuse ends of the bands. In many cases the intensity changes gradually from head to head, there being heavy absorption at the sharp edge, the spectrum growing uniformly brighter to the next line of demarcation.

Sidgreaves, on comparing the spectrum of *o Ceti* with that of *a Herculis* and other third-type stars, found a difference in the wave-length of the same band in different stars. For the head at λ 5447 in *o Ceti*, he found the position of λ 5458 in *a Herculis*, and intermediate values for *a Orionis* and *β Pegasi*. He suspected these discrepancies to be due to instrumental causes, but of this he was not certain. His work being done with an objective prism, he had no comparison spectrum with which to test the reality of the observed differences.

Along with the work on *o Ceti* in 1902, plates were taken of *a Herculis*, *β Pegasi*, *ρ Persei*, *a Ceti*, and *a Orionis*. As these stars are all bright, the exposures on them were comparatively short, from five minutes to one hour. Isochromatic plates were used, so that a range of spectrum as far to the red as λ 5600 was covered. They were measured only for the positions of the heads of the bands. In the spectrum of *Mira* there are few dark lines shown in the region of the bands, but in the others many lines were recorded. Where there are more lines the bands are less prominent, and in the case of *a Ceti* and *a Orionis*, only three bands could be measured. All of these stars are on the regular Mills spectrograph program, and their radial velocities have been determined from their dark line spectra in the region of $H\gamma$. As the wave-lengths of the bands must be affected by the radial velocities, it is necessary to apply to each observed wave-length a corresponding correction. In Table X is given, first the observed wave-lengths of the head of each band, already corrected for the orbital motion of the Earth. The accompanying correction is that which must be applied to each wave-length in order to reduce it to what it would be if the star's radial velocity referred to the Sun were zero. The mean result from the five stars has been taken after applying these corrections.

All bands visible on the plates were measured; and if the position of a band is not given for a star, it was not apparent. The results for any star are from all the plates of that star, except in the case of *a Herculis*, where one of the plates was a "Crown" plate and showed nothing to the red of λ 4954.

The results obtained by Sidgreaves, Vogel, and others are

inserted for comparison. The corrections given by Sidgreaves in *Monthly Notices*, **59**, 509, have been applied to his first published wave-lengths. Vogel's photographs did not extend to the red of λ4800. The results of visual observations of the bands in third-type stars are taken from Frost's Scheiner.

TABLE X.

Measures of Bands.

o Ceti Several Plates +62 km	*α Herculis* 2 and 1 Plate −34 km	*ρ Persei* 2 Plates +27 km	*β Pegasi* 2 Plates +8 km	*α Orionis* 4 Plates +18 km	*α Ceti* 2 Plates −25 km	Corrected Mean, Excluding *o Ceti*	*o Ceti* Corrected for +62 km	Sidgreaves, *o Ceti*	Vogel, *o Ceti*	Vogel and Others, 3d-Type Stars, Visual
4314.3 −0.9	......	......	......	......	......	......	4313.4	....	....	....
4353.6 −0.9	......	......	......	......	......	......	4352.7	4352	....	....
4395.9 −0.9	......	......	......	......	......	......	4395.0	4395	....	....
4422.4 −0.9	4421.0 +0.5	......	......	......	......	4421.5	4421.5	4421	4422	....
4463.0 −0.9	......	......	......	......	......	......	4462.1	4460	4462	....
4505.7 −0.9	......	......	......	......	......	......	4504.8	4504	4506	....
4548.8 −0.9	......	......	......	......	......	......	4547.9	4546	4545	....
4585.0 −0.9	4583.9 +0.5	4584.8 −0.4	......	......	......	4584.4	4584.1	4583	4581	4608
4626.8 −1.0	4625.7 +0.5	4626.8 −0.4	......	......	......	4626.3	4625.8	4625	4622	....
4669.6 −1.0	4667.1 +0.5	4667.9 −0.4	......	......	......	4667.6	4668.6	4669	4666	....
4714.2 −1.0	4713.6 +0.5	......	......	......	......	4714.1	4713.2	4714	4710	....
......	4736.6 +0.5	......	......	......	......	4737.1	......	4736	....	....
4760.0 −1.0	4760.0 +0.5	4761.3 −0.4	4761.8 −0.1	......	......	4761.0	4759.0	4758	4755	4767
4804.2 −1.0	4803.5 +0.5	4804.9 −0.4	4805.4 −0.1	......	......	4804.6	4803.2	4803	....	....
4842.8 −1.0	......	......	......	......	......	......	4841.8	4842	....	....
......	......	4848.8 −0.4	......	......	......	4848.4	......	....	....	....
......	......	......	......	......	......	......	......	4892	....	....
4954.1 −1.0	4953.0 +0.6	4954.7 −0.4	4954.6 −0.1	4955.4 −0.3	4954.7 +0.4	4954.5	4953.1	4951	....	4962
......	......	......	......	......	......	......	......	4998	....	....
......	......	......	......	......	......	......	......	5046	....	....
......	......	......	......	......	......	......	......	5074	....	....
......	......	......	......	......	......	......	......	5098	....	....
......	......	......	......	......	......	......	......	5135	....	....
5167.0 −1.1	5165.0 +0.6	5166.6 −0.5	5166.3 −0.1	5165.8 −0.3	5165.4 +0.4	5165.8	5165.9	5162	....	5169
......	......	......	......	......	......	......	......	5237	....	5244
5308.3 −1.1	......	......	......	......	......	......	5307.2	5306	....	....
5358.8 −1.1	......	......	......	......	......	......	5357.7	5356	....	....
......	......	......	......	......	......	......	......	5406	....	....
5439.4 −1.1	......	......	......	......	......	......	5438.3	....	....	....
5447.9 −1.1	5446.9 +0.6	5447.9 −0.5	5446.7 −0.2	5446.3 −0.3	5445.9 +0.5	5446.8	5446.8	5447	....	5453
5498.0 −1.1	5496.5 +0.6	5497.1 −0.5	......	......	......	5496.8	5496.9	5498	....	....

Several objects measured as bands by the writer were not recorded by Sidgreaves; but they are not prominent, and we should not expect different observers with different instruments to agree as to details. Sidgreaves recorded more bands than I did to the red of λ 4954. The plates taken with Spectrograph I are underexposed in this region, and only the more prominent bands show.

A comparison of the corrected positions for *o Ceti* with the

means for the other stars shows that there is little difference in the wave-lengths, except that due to different radial velocities.

It is interesting to note what effect the application of the corrections for radial velocities has upon the agreement of the results. Residuals have been formed by subtracting the mean positions from those of each of the five stars. The sum of the squares of the residuals is reduced from 12.34 to 5.46 by the application of the corrections. This diminution of the residuals shows the validity of the assumption that the positions of the bands are the same in the five stars observed, and that the bands in each star have the same displacement, due to velocity, as have the fine, dark lines in the $H\gamma$ region.

However, the case is not clear with *o Ceti*. The correction for + 62 km changes the sum of the squares of the residuals, obtained by subtracting the mean wave-lengths of the other stars from those of the *o Ceti*, from 10.84 to 10.09. The corrections change the algebraic sum of the residuals from + 5.8 t.m. to − 5.3 t.m. This result is not surprising when it is remembered that all poorly defined bands were included in forming the residuals.

Judging by the accordance of the individual results, and allowing for any chance of personal error in the measures, it seems unlikely that the position of a sharply defined head of band should be in error by as much as one tenth-meter.

As far as I know, the identification of the bands of the third-type stars has not been accomplished. If the division at λ 5165.9 be considered as the head of a bright band, it is in close agreement with the head of the third carbon band at λ 5165.3, as measured by Kayser and Runge. The head at λ 4737.1, measured in *a Herculis*, may also correspond to their fourth carbon band, λ 4737.2. These two coincidences are the only ones I have found and we certainly need more evidence before drawing any conclusions from them.

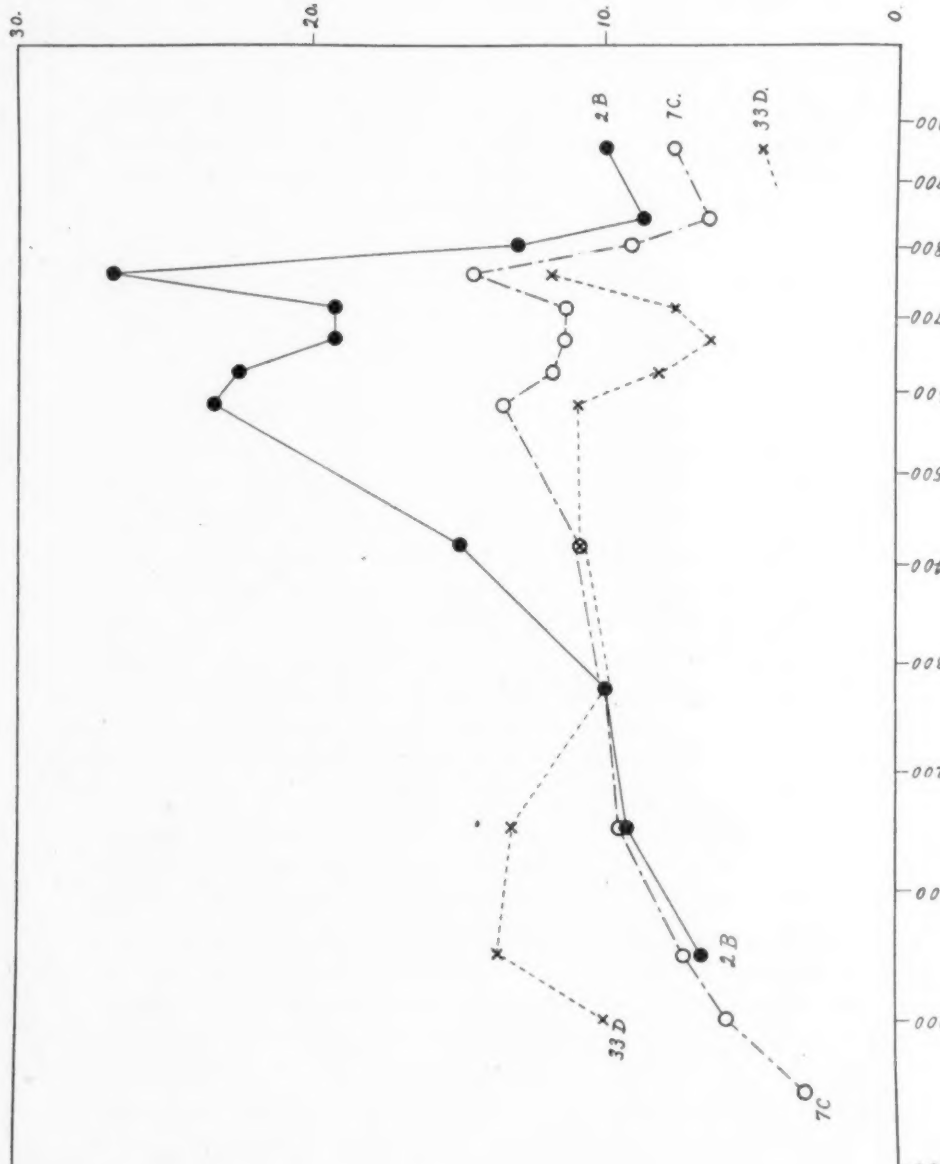
VARIATIONS OF INTENSITY IN THE CONTINUOUS SPECTRUM.

Sidgreaves found that the continuous part of some regions of the star's spectrum changed in relative intensity as the star grew fainter. These changes have been verified in the present work.

In order to estimate the relative brightness of different parts, it was necessary to have a standard scale which should look like the spectrum of the star. An exposure on the sky of about one minute gives a strong solar spectrum not unlike that of a solar-type star. The telescope with Spectrograph I attached was pointed to the north pole at about noon on a clear day, and a series of twenty-five plates with carefully timed exposures varying from 1^s to 80^s was taken. These plates, all of the same emulsion, were developed simultaneously in the same tray, so that all would receive the same photographic treatment. The 1^s exposure gave a faint image and the 80^s an overexposed one. As on any one plate the amount of the silver deposit varies in different parts of the spectrum, the region between the iron lines at λ 4046 and λ 4072 was adopted as standard.

These plates were used for the purpose of comparing the intensities on different plates of *o Ceti* and also on different parts of the same plate. The method of using the scale plates was as follows: The plate of the star was placed film up on the table of the measuring microscope. The different scale plates were then successively placed film down on the star plate and viewed with a low power. The scale plate whose spectrum equaled the star spectrum in density was selected, and the number of seconds which it had taken to produce the image on the scale plate was called the intensity of the star spectrum. Of course, the lines in the star spectrum interfered with the estimates, but it was usually possible to find a space where there were apparently no absorption lines. In all cases the darkest patch of spectrum in the immediate vicinity on the negative was used.

Since we do not know the exact relation between time of exposure and density of the photographic image, the estimates made with the scale plates do not give us absolute intensities. There are also many errors introduced by instrumental causes. Among other sources of error is that due to the non-achromatism of the large objective. The proportions of light of different wave-lengths which enter the slit must vary with the quality of the seeing, and the care used in guiding. The star image which falls on the slit is not homogeneous, but is composed of a central



30.
20.
10.
0
30
20.
10.
0.
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
3900
2B
7C.
33D.
2B
33D
7C

FIG. 7.

PLATE XV.

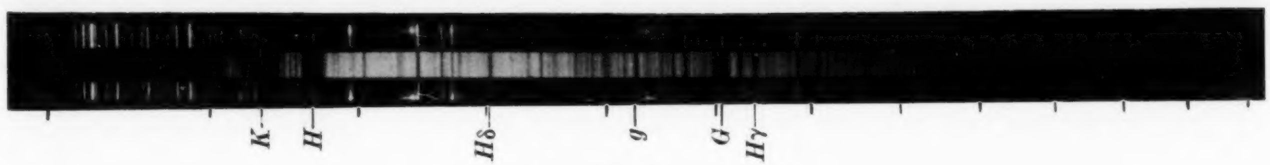


FIG. 2.—Solar Spectrum (sky).

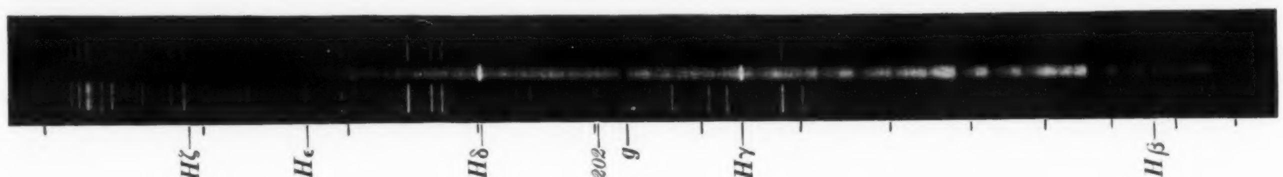


FIG. 3.—o *Ceti*, 1902 July 6. 7 C.

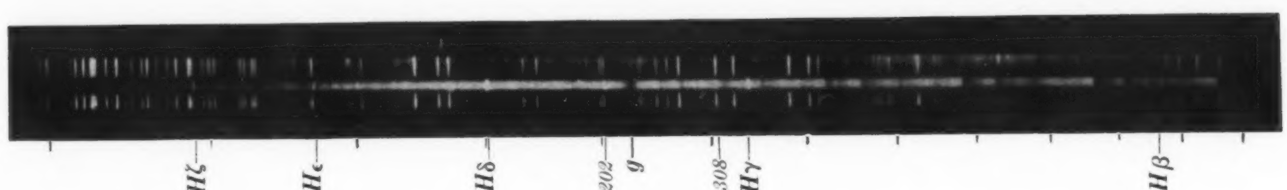


FIG. 4.—o *Ceti*, 1902 August 4. 27 D.

disk of $H\gamma$ light surrounded by concentric circles of light of longer and shorter wave-lengths.

The effects of different conditions of seeing and guiding were determined from plates taken of other stars, and while some differences were noticed, they were small compared with the changes observed in the case of *o Ceti*.

Fig. 7 gives the "intensity curves" of *o Ceti* from three plates, which were all of the same emulsion. The intensities of the same portions of the star spectrum were estimated on each plate by means of the scale. These estimates were plotted, and, in the figure, the lines join the estimates without reference to the intensities of the other parts of the spectrum. The images on the different plates being as a whole unequal in density or blackness, the portion near λ 4275 was made equal to 10, and the estimated intensities of other portions were changed to correspond. All estimates to the red of λ 4400 refer to the brighter portions, which may be heads of bright bands.

Sidgreaves's plates showed that as the star declined in brightness, the intensity of the bright portions of the spectrum between λ 4300 and λ 5000 grew less relatively to that of the region near λ 5500. My plates show a decrease in intensity of the region from λ 4300 to λ 5000 relative to the continuous spectrum from λ 4000 to λ 4300.

Figs. 3 and 5 (Plates XV and XVI) show the changes well. Plate No. 2B is not in excellent focus and is therefore not reproduced.

It should be remembered that the solar spectrum, Fig. 2 (Plate XV) is from a negative of the sky, on a lantern-slide plate whose sensibility curve is very different from that of the Crown plates. The maximum intensity of the continuous spectrum on a Crown plate is about λ 4600 for a solar-type star.

These changes in intensity have been described as changes in the continuous spectrum, but they may be simply the fading out of some bright bands.

BRIGHT LINES.

The most noticeable and interesting features in the spectrum of *o Ceti* are the bright lines. The great brilliancy of some of

the hydrogen lines, when the star was near its maximum, has been recorded by several observers.

The peculiar fact was noticed that $H\alpha$, $H\beta$, and $H\epsilon$ were apparently missing, while others of the hydrogen series were very bright. Photographs, which showed $H\gamma$ and $H\delta$ as intense, gave no trace of $H\beta$ and $H\epsilon$. Sidgreaves, in 1898 and 1899, found something which from its position might be the bright $H\beta$, but he did not consider it as certain. It has been seen bright on some plates at Harvard.[1] Mr. Wright found $H\epsilon$ distinctly bright on a plate which he had taken in August 1901. Figs. 3 to 5 show additional evidence on this point. $H\beta$ and $H\epsilon$ were recorded as bright lines on all the dense negatives taken with Spectrograph I. They seem to have grown stronger relatively to the other hydrogen lines and also to the continuous spectrum as the star grew faint.

An attempt was made to observe $H\alpha$ visually, but without

TABLE XI.

Measures of Bright Lines.

λ	7C	9E	13E	14F	18F	25F	27D	28D	2235D
3751.2–	..	..	..	..	..	..	—	..	..
3771.52	..	..	..	..	..	..	—	..	..
3798.76	*04*	..	03	..	..	..	02	..	..
3836.20	*04*	..	05	..	..	*07*	08	00	*03*
3853.51	..	..	01	..	..	..	00	00	..
3889.91	03	..	01	11	..	*08*	03	02	*12*
3906.36	00	..	03	..	..	*04*	03	09	*11*
3908.18	..	..	..	..	..	..	02	*03*	..
3933.45	..	..	..	..	..	..	*09*	09	..
3939.10	..	..	..	..	..	..	*07*	07	..
3968.49	..	..	..	...	..	.	*10*	10	..
3970.87	11	..	12	..	..	*04*	*01*	03	*20*
4007.74	*01*	..	01	..	..	..	..	..	..
4102.66	*03*	00	08	00	..	*03*	03	*01*	*03*
4202.91	*04*	..	06	..	..	00	*08*	*06*	14
4216.71	..	..	..	..	..	11	*20*	09	..
4234.12	..	..	*03*	..	..	02	*13*	03	10
4308.70	..	..	..	..	..	*02*	*03*	06	..
4341.33	09	*04*	10	13	..	*15*	*08*	00	*04*
4373.61	..	..	..	..	..	..	..	—	..
4376.78	..	..	..	..	..	*05*	07	*01*	..
4571.82	..	..	..	..	..	*20*	*07*	28	..
4862.34	..	..	23	..	*09*	*14*	02	*03*	..

[1] *Harvard Annals*, **28**, Part I.

PLATE XVI.

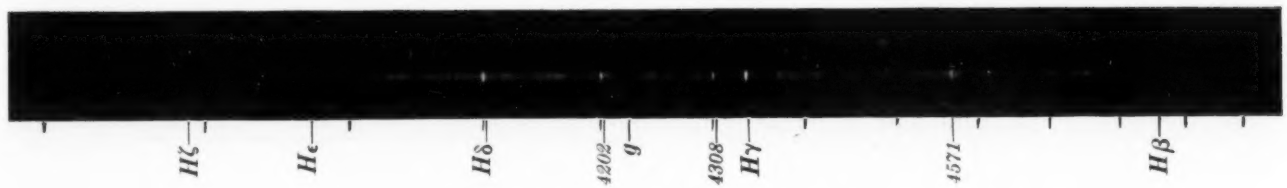


FIG. 5.— o *Ceti*, 1902 September 6. 33 D.

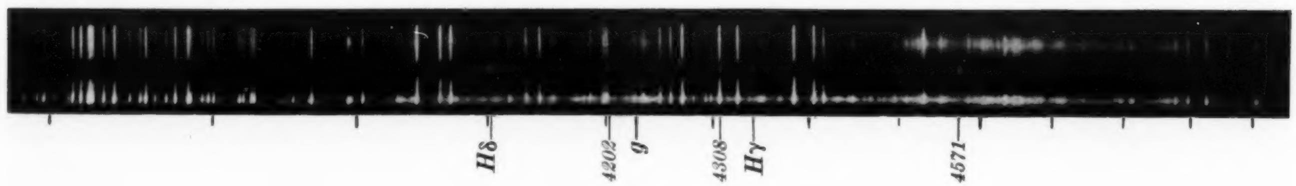


FIG. 6.— o *Ceti*, 1902 October 4. 42 A.

success, on the night of September 6, 1902, when the instrument was changed to adapt it for visual work. Corresponding to the bright well-defined *Ha* of the comparison spectrum there was continuous spectrum, but no bright line in the star. Mr. Wright was present and verified the observation. *Ha* should be looked for when *Mira* is again at a maximum.

Table XI gives the measures of all the bright lines which appeared, sooner or later, during the course of the work. The same scheme of residuals is used as in Table III.

Below is given a list of places which have the appearance of bright lines, but which, in the judgment of the observer, are bright spaces between absorption lines. Some of the places were measured on only one plate, but the wave-lengths are probably as accurate as those of the absorption lines.

λ 3978.7	λ 4213.0
3998.5	4427.9
4002.7	4434.5
4031.5	4512.6
4179.6	4777.6

From the residuals of Table XI the probable error of the wave-length of a bright line, determined from one plate, is found to be ± 0.06 t.m. The wave-lengths of the bright lines show no more change than do those of the dark lines. The average residual for each plate has been computed and there is no sign of variable position. A comparison of these average residuals with those of the dark lines is as follows:

TABLE XII.

Date	Plate No.	Dark Lines	Bright Lines
1902, July 6	7 C	+0.02	+0.01
16	13 E	+0.06	+0.04
August 4	25 F	−0.03	−0.03
11	27 D	−0.02	−0.03
25	28 D	−0.03	+0.03
1901, August 17	2235 D	+0.02	−0.04

These average residuals are all so small that the agreement in sign for some cases is of little significance.

Table XIII gives the identification of some of the bright lines. There can be no doubt that the hydrogen series is present. Metallic lines which seem to coincide in five cases are given, but, in spite of the accuracy of the measures, we must consider the question of their identity to be still open.

TABLE XIII.

Identification of Bright Lines.

o *Ceti* λ	Tabular λ	Displacement t. m.	Substance	Authority for λ
3751.2-	3750.15	+1.0-	$H\kappa$	Ames
3771.52	3770.7-	+0.82	$H\iota$	Ames
3798.76	3798.0-	+0.76	$H\theta$	Ames
3836.20	3835.6-	+0.60	$H\eta$	Ames
3853.51				
3889.91	3889.15	+0.76	$H\zeta$	Ames
3906.36	3905.66	+0.70	*Si* 12	Rowland
3908.18				
3933.45				
3939.10				
3968.49				
3970.87	3970.18	+0.69	$H\epsilon$	Rowland
4007.74				
4102.66	4101.89	+0.77	$H\delta$	Wright
4202.91	4202.20	+0.71	*Fe* 8	Rowland
4216.71				
4234.12				
4308.70	4308.08	+0.62	*Fe* 6	Rowland
4341.33	4340.63	+0.70	$H\gamma$	Rowland
4373.61				
4376.78	4376.11	+0.67	*Fe* 6	Rowland
4571.82	4571.26	+0.56	*Mg* 5	Rowland
4862.34	4861.53	+0.81	$H\beta$	Rowland

It should be noticed that a bright line developed on each side of each of the strong dark calcium lines, *g*, H and K. Without looking at the plates, this might seem to be due to a double reversal of the calcium lines. Their appearance is not such, however. Mr. Wright also examined the plates with this in mind, and in his judgment the lines are separate bright lines, and the phenomenon is not one of double reversal.

Several attempts were made, in June and July 1902, to secure photographs of the spectrum of *Mira*, with the regular three-prism instrument. It was impossible, however, to make an exposure long enough to record the continuous spectrum. The only features recorded were $H\gamma$ and two other bright lines. $H\gamma$

was single on all the plates. It seemed nearly monochromatic, but was a little sharper on the violet than on the red side. It had the same appearance as that found by Campbell in 1898 at about the same interval after the star's maximum. In 1898 he found that $H\gamma$ was triple from five to two weeks before maximum. Before observations of *o Ceti* were begun in 1902, it had been intended to make polariscopic tests for Zeeman effects in the bright lines; but they were found single on the first photographs and no observations for polarization were attempted. These should certainly be made when it is again possible to observe the star at maximum. Measures of the three-prism plates give the following displacements of $H\gamma$ in tenth-meters.

TABLE XIV.

Date	Plate No.	t.m.
1902, July 2	2446 F	+0.65
2	2447 A	+0.68
21	2470 D	+0.65
August 18	2505 E	+0.61
		Mean +0.65 t.m.

It is interesting to compare the measures of plates taken in 1902 with those of 1898. Campbell also observed the bright lines near λ 4308 and λ 4376. They were also measured on the high-dispersion plate of August 18, 1902. In the following scheme, under the heading "Bright Lines" is given the actual observed displacement of each bright line, corrected for the

TABLE XV.

Line	Campbell, 1898		Stebbins, 1902		
	Three Prisms		Three Prisms. Bright Lines		One Prism Dark Lines, +66km
	Bright Lines t.m.	Dark Lines, +66km t.m.	t.m.	t.m.	t.m.
$H\delta$ 4101.89	+0.64	+0.85	......	+0.77	+0.90
Fe? 4308.08	+0.60	+0.89	+0.61	+0.62	+0.95
$H\gamma$ 4340.63	+0.64	+0.90	+0.65	+0.70	+0.96
Fe? 4376.11	+0.61	+0.91	+0.66	+0.67	+0.96

earth's motion. Under "Dark Lines" is given an assumed displacement which corresponds to that of the absorption lines in the spectrum.

The dark lines in this region of the spectrum are apparently displaced about 0.25 tenth-meter farther to the red than are the bright lines. The results obtained with one prism are systematically larger than those obtained with three prisms. This may be partly due, in the case of $H\gamma$ and $H\delta$, to overexposure on many of the plates. Since the lines seem to shade off towards the red, greater exposure probably slightly increases the apparent wave-lengths. However, since the displacement of the other hydrogen lines, which where not overexposed, is about the same as that of $H\gamma$ and $H\delta$, this effect is probably not large. The difference between the results of 1898 and 1902 is due, no doubt, to personal errrors.

The bright lines at $\lambda\lambda$ 4308 and 4376, marked as possibly due to iron, are of peculiar interest. They were recorded in Table VI as dark lines. The appearance of each, on some of the plates, is of a bright line with an adjacent dark one on the red side. If the bright lines be due to iron, they are displaced by the same amount as the bright hydrogen lines; and if iron produces the absorption components, the displacements are equal to those of other dark lines.

A glance at the series of plates showed that there were many changes of intensity among the bright lines, both relative to each other and to the continuous spectrum. Lines not visible on the earlier plates became more intense than the hydrogen lines which were so bright near maximum.

In order to estimate the amounts of the changes, a scale was made by the following method: An occulting strip was arranged in front of the photographic plate in the three-prism Mills spectrograph in such a manner that only the line λ 4308.081 of the iron spectrum reached the plate. A two-second exposure gave just a trace of an image of this line, whereas ten minutes produced an overexposed image of greater breadth and blackness than was ever obtained of the bright $H\delta$ star line. The plate-holder was moved by small successive steps along in its cell,

and a series of carefully timed exposures, varying from one second to ten minutes, was made. At intervals the current was switched to the other side of the comparison apparatus and an image of the same line due to an exposure of five seconds was recorded on the plate. These extra images served as a rough test of the constancy of the light, and as reference points, for the scale. The exposures were all made on the same plate, and the different images received the same photographic treatment.

The bright lines of *o Ceti* were compared with this scale, and to each line was assigned as intensity, the number of seconds required to produce the equal line in the scale. Independent estimates of the same line made in this manner at different times are accordant with each other.

As the density of the star spectrum, as a whole, varied greatly on the different plates, the intensities of the same line on different plates are not comparable, unless they are referred to a common standard. If the intensity of a bright line, as estimated with the scale, be divided by the intensity of the continuous spectrum on the same plate, we get what we might call the intensity of the bright line referred to the continuous spectrum. The quotients formed in this manner will be referred to as the intensities of the bright lines. It is evident that long and short exposures of the star taken on the same night should give approximately the same intensities of the bright lines. As has already been shown, there is evidence that the intensity of the continuous spectrum varied in different parts as the star faded. The intensities of bright lines were, therefore, all referred to the portion of the continuous spectrum between λ 4102 and λ 4227.

The development of the bright lines is shown in Table XVI. It happens that the faintest bright line to which an intensity was assigned is called 1. On plate 27D the line at λ 3908.18 was estimated with the bright line scale to be of intensity 3.5. The intensity of the continuous spectrum between $H\delta$ and g was called 24. Dividing 3.5 by 24 and multiplying by 10, an arbitrary factor, the resulting intensity of the bright line is 1. On

the plate 2B the scale value of the $H\delta$ line was 250, and the continuous spectrum was of intensity 6. The resulting intensity of $H\delta$ is therefore 420. These numerical operations are crude, but they are as accurate as necessary.

In Table XVI a period (.) indicates that the image on the plate is dense enough, and that the definition is good enough to show the line as bright, had it existed when the plate was taken, but that it was not visible. A dash (—) means that the line did not appear on the plate, but that, judging from the evidence furnished by other plates, it would have been recorded with a longer exposure. Where the observer is unable to state whether the line existed or not, the space has been left blank. Plates numbered 13E, 18F, 21F, and 25F, and those of Mr. Wright, are Isochromatic, and are therefore not strictly comparable with the Crown plates.

The short exposures 3C and 4E give results fairly consistent with the long exposure 2B, taken on the same night. The plates 8D and 9E do not agree at all with the denser negative of 7C. This discordance shows that the estimates are very rough.

Another source of error is the effect of widening the slit for the long exposures. This might easily produce a progressive change in the apparent intensity of the lines relative to the continuous spectrum, but it certainly could not produce such great variation among the lines themselves.

The changes of the lines are shown graphically in Figs. 8–13. The intensities are represented by ordinates. It will be seen how the hydrogen lines, $H\gamma$ and $H\delta$, decreased in intensity as the star grew faint. In Fig. 8, Plate 2B, the intensity of $H\gamma$ has been arbitrarily reduced to accord with the evidence furnished by the other plates taken on the same night. Figs. 8–12 truthfully indicate the development of the bright lines from $H\delta$ to the red. In Fig. 13 and to the violet of $H\delta$ on the other plates the data are insufficient on account of underexposure. The line at λ 4007 was the only one which certainly disappeared during the interval covered by these six plates. The development of the line at λ 4571 was remarkable. This line, which is perhaps due to magnesium, did not appear until the star was of about

TABLE XVI.

Intensities of Bright Lines.

	Crown Plates						Isochromatic Plates				Crown Plates						Isochromatic	
Date	1902 June 27			July 6			July 16	July 22	July 29	Aug. 4	Aug. 11	Au. 25	Sept. 6	Sep 22	Oct. 4	Oct. 26	1901 Aug. 3	Aug. 17
Plate Number	2B	3C	4E	7C	8D	9E	13E	18F	21F	25F	27D	28D	33D	39D	42A	48A	2211C	2235D
Mag. of Star		3.8			4.1		4.6	5.1	5.3	5.4	5.6	6.4	7.0	7.0	7.8	8.5	—	—
Intensity of Continuous Spectrum	6	2.0	1.5	9.5	1.4	2.0	7.5	7	7	11	24	17	6.5	7	5	2.0	2.9	9
Hκ 3751.2–	—	—	—	—	—	—	—	—	—	—	faint	—	—	—				—
Hι 3771.52	—	—	—	—	—	—	—	—	—	—	2	—	—	—				—
Hθ 3798.76	—	—	—	3	—	—	3	—	—	—	2	—	—	—				—
Hη 3836.20	9	10	—	12	—	—	13	8	4	2	6	4	4	—				6
3853.51	.	.	.	.	.	.	3	—	—	—	4	4	—	3				.
Hζ 3889.91	33	40	20	34	27	—	41	26	21	14	17	11	13	7	5		14	16
3906.36	4	—	—	7	—	—	6	4	—	2	5	5	6	5				4
3908.18											3	3	—	—				
3933.45											1	2	—	3				
3939.10											4	5	7	8				
3968.49											4	5	8	5				
Hε 3970.87	4	—	—	9	—	—	12	13	13	11	17	14	17	10				4
4007.74	6	—	—	9	—	—	—	4	.	.	.	.	.	.				.
Hδ 4102.66	420	600	410	220	140	50	290	390	390	260	120	100	90	40	30	13	140	190
4202.91	10	—	—	9	—	—	13	14	19	21	12	21	32	31	30	40	21	17
4216.71	.	.	.	.	.	.	.	.	.	6	4	6	14	14	13			.
4234.12	.	.	.	.	.	.	8	—	7	7	4	6	11	6	12			7
4308.70	.	.	.	.	.	.	.	.	12	13	9	13	35	37	48	60		.
Hγ 4341.33	420	520	280	130	90	34	160	240	190	170	80	70	70	30	24	13	80	60
4373.61	.	.	.	.	.	.	.	.	.	3	2	5	9	8	6			.
4376.78	.	.	.	.	.	.	.	11	8	8	6	8	15	15	12			.
4571.82	.	.	.	.	.	.	.	.	.	12	7	15	28	60	90	75		.
Hβ 4862.34	17	—	—	10	—	—	8	5	5	6	8	9	11	12	11			3

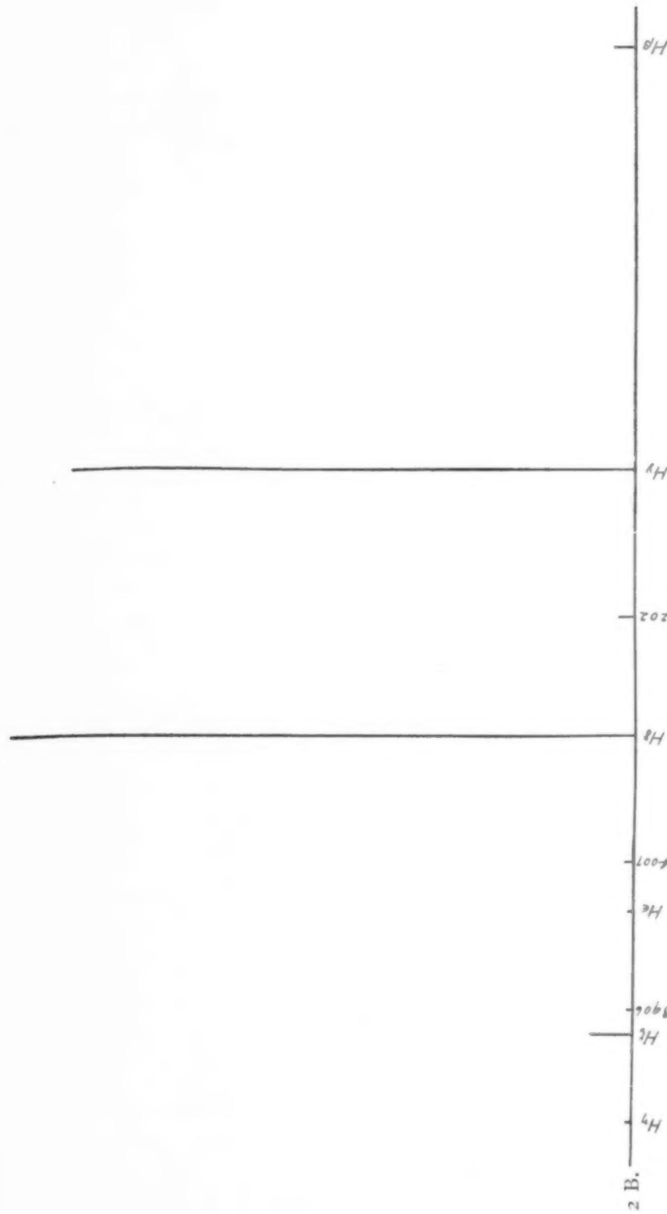


FIG. 8.

magnitude 5.4, and as the star grew fainter it became the most prominent object in the spectrum.

The images on the plates following 48A are not strong enough to give results which can be entered in Table XVI. A brief summary of what was found on the plates may be of interest:

54A. Bright lines 4202, 4308, apparently present, 4571 certain. No trace of any continuous spectrum.

58A. Bright lines 4202, 4308, 4571 all certain. Faint continuous spectrum from λ 4000 to λ 4800.

59A. Bright line 4202 not found. 4308, 4571 present. Faint continuous spectrum from λ 4000 to λ 4150, also from λ 4200 to λ 4585.

On 58A and 59A the continuous spectrum was visible in the $H\gamma$ and $H\delta$ regions, but no trace of a bright line was seen in either case. The evidence furnished by these later plates therefore strengthens the conclusion that the bright hydrogen lines disappeared at minimum. $H\gamma$ and $H\delta$ would certainly have been recorded if they had remained as intense as they were a month preceding minimum. Figs. 8–13 show that $H\gamma$ and $H\delta$ were growing fainter as the star declined, and the lines λ 4202, λ 4308, and λ 4571 were increasing in intensity as far as Plate 48A. I am not prepared to say whether the intensities of these last three lines increased or decreased after that time, but they did not change much. It is certain that no new bright lines appeared which were as prominent as those already under observation, for the plates were carefully examined. In fact the lines on Plate 54A were entirely overlooked on the first examination.

While the method of estimating intensities here presented is subject to many errors, it affords a better idea of the changes than be could given by a mere description. All the estimates with the bright-line and continuous-spectrum scales were made in such a way as to avoid personal bias. The observer did not know, when using the scales, how the final intensities would come out, and the relative changes observed in the continuous spectrum and in the bright lines are real.

Until this star has been successfully followed through all its phases, it is obviously too soon to advance any theory to account for the observed changes in its spectrum or in its brightness.

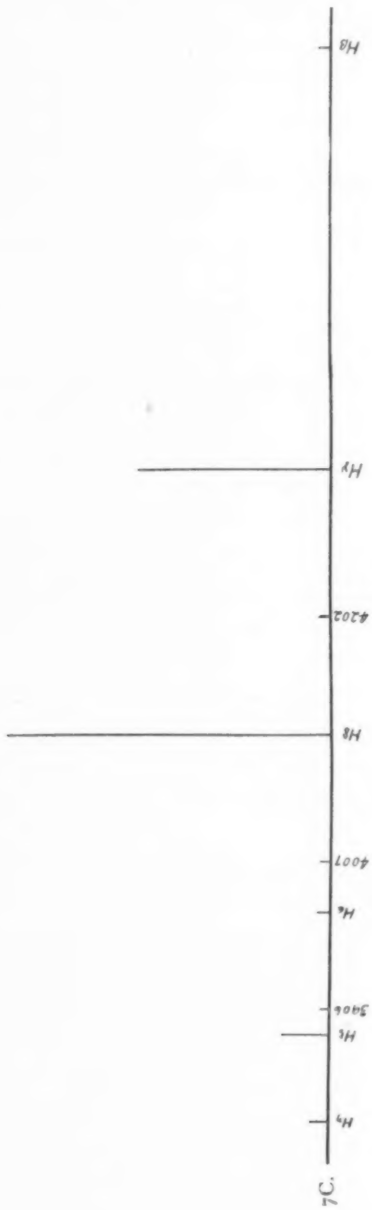

7C.
Hβ
Hγ
4202
Hδ
4007
Hε
3906
Hζ
Hη

FIG. 9.

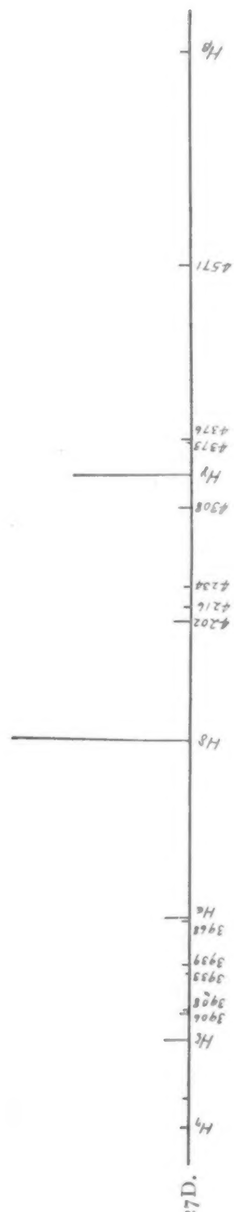

27D.
Hβ
4571
4376
4373
Hγ
4308
4234
4216
4202
Hδ
Hε
3968
3939
3933
3908
3906
Hζ
Hη

FIG. 10.

The light gathering power of the great refractor is not sufficient to follow the spectrum satisfactorily, at least not on the dispersive scale used by me. An ideal equipment for work on variables would consist of a large reflector which could be used for this purpose alone, with spectrographs of various dispersive powers arranged for use in all parts of the spectrum.

The apparent constancy of radial velocity is strong evidence that the variations in brightness are not due to the influence of a companion star, unless, indeed, the companion were of very small relative mass, were moving in a very eccentric orbit and approached very close to the primary. The displaced system of bright lines could not belong to such a companion, as their wavelengths are apparently constant. The large irregularities in the period of the light curve practically preclude the question of a binary system, though perhaps not absolutely so.

The remarkable distribution of light in the hydrogen series seems as yet impossible to explain. Miss Clerke has explained the apparent absence of $H\epsilon$ by assuming the hydrogen to be at a lower level in the star's envelope than the calcium layer, the H calcium absorption destroying the $H\epsilon$ radiations. This theory may still be true, though the existence of a faint bright $H\epsilon$ has been proven. However, $H\beta$ and $H\alpha$ are much more reduced in intensity than is $H\epsilon$; and with them there is no evidence of over lying absorption strata. It is usually expected that the bright hydrogen series will diminish in intensity from red towards the violet. This appears to hold even for new stars, in which the disturbance has been very sudden, though exception should perhaps be made for $H\alpha$ when new star spectra approach the nebular form. The supposition that in *Mira* the hydrogen series may regularly decrease in brightness from violet to red is not tenable, as the diminution from $H\gamma$ to $H\beta$ is entirely too great. Inasmuch as the bright lines are strongly shifted (to the violet with reference to the dark-line system) from their normal positions apparently by causes other than radial velocity and pressure, it seems probable that the peculiarities of the hydrogen-line intensities are due also to causes now unknown to us. The presence of the bright iron lines λ 4308 and λ 4376, the absence of others

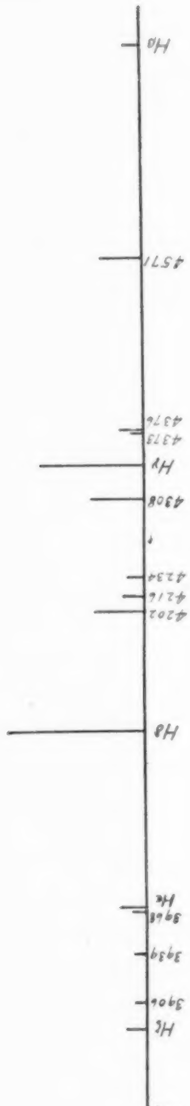


FIG. 11.

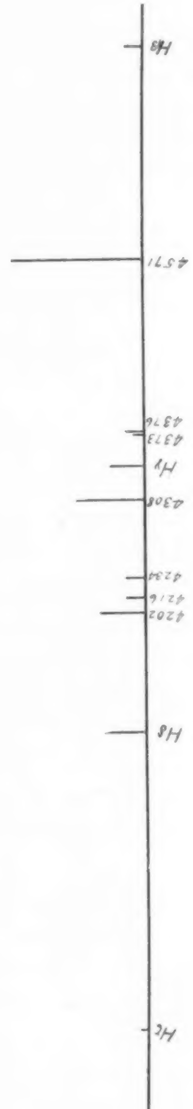


FIG. 12.

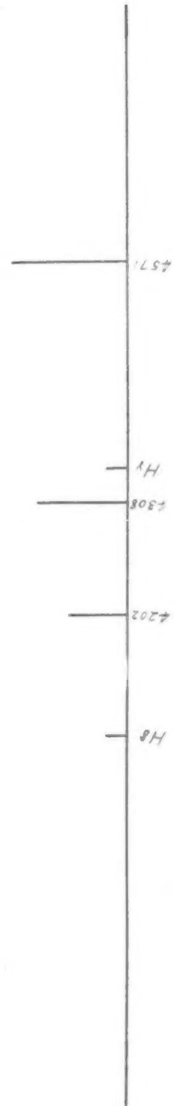


FIG. 13.

of the same element, and the diversity of structure observed by Campbell in the triple $H\gamma$ and $H\delta$ bands are perhaps due to similar unknown causes.

The great variations of relative intensity observed in the hydrogen and other bright lines, and in the continuous spectrum, show that the star's decrease in light is produced by other causes than general absorption.

Considering all the evidence, it seems reasonably certain that the star's variation in brightness is due to the action of internal forces.

I beg to acknowledge my indebtedness to Director Campbell, who provided the necessary apparatus and made valuable suggestions during the course of the work; to Messrs. Wright and Reese, for continual advice and assistance, and to Dr. H. D. Curtis, for enlarging the negatives for reproduction.

OBSERVATIONS OF THE BRIGHTNESS OF *o CETI* IN 1902–1903.

The brightness of *o Ceti* was observed by Argelander's method about once a week, beginning with June 23, 1902. At first the star's magnitude was determined with the naked eye or opera glass. After it had become too faint to be seen with an opera glass, the three-inch finder of the twelve-inch telescope was used.

In order to avoid prejudice, the observations in "grades" were made, recorded, and then laid aside, to be reduced a month or two later. When observing, I did not know the magnitude of any of the comparison stars, and in but few cases did I remember what the estimate on any previous night had been.

The magnitudes of all stars brighter than 7.00 were taken from the *Harvard Photometry*, *Harvard Annals*, **45**. For the fainter stars the adopted magnitudes are those of H. M. Parkhurst, given in **29**, 144 of the same publications. No stars that are not in one of these two sources were used for the comparisons.

The value of one "grade" has been determined from the observations to be 0.11 magnitude. However, most of the comparisons were made and reduced in such a manner that the resulting magnitude is independent of the value of a grade. For the sake of uniformity, all estimates were made in grades, and it

was tried to keep the value of one grade as nearly constant as possible. In reducing observations where *o Ceti* was compared with two stars, one brighter and one fainter, the magnitude of the variable has been taken proportionally between them. In taking the mean of several estimates, an estimate derived from two stars has been given twice the weight of an estimate based

TABLE XVII.

Reference Letters and Magnitudes Adopted for the Comparison Stars.

Letter	Mag.	*B. D.*	Name	R. A. 1900	Decl. 1900
a	3.64	−10° 240	η *Ceti*	$1^h 03^m.6$	−10° 43′
b	3.64	+ 2° 422	γ *Ceti*	2 38.1	+ 2 49
c	3.71	−16° 295	τ *Ceti*	1 39.4	−16 28
d	3.86	− 8° 244	θ *Ceti*	1 19.0	− 8 42
e	3.90	− 0° 406	δ *Ceti*	2 34.4	− 0 06
f	3.91	+ 2° 317	α *Piscium*	1 56.9	+ 2 17
g	3.96	−11° 359	ζ *Ceti*	1 46.5	−10 50
h	4.30	+ 7° 388	ξ^2 *Ceti*	2 22.8	+ 8 01
i	4.33	+ 9° 359	μ *Ceti*	2 39.5	+ 9 42
j	4.46	+ 8° 273	ο *Piscium*	1 40.1	+ 8 39
k	4.62	+ 4° 293	ν *Piscium*	1 36.2	+ 4 59
l	4.73	+ 8° 455	λ *Ceti*	2 54.4	+ 8 31
m	4.88	+ 2° 290	ξ *Piscium*	1 48.4	+ 2 42
n	5.05	+ 4° 418	ν *Ceti*	2 30.6	+ 5 09
p	5.22	− 4° 260		1 37.7	− 4 11
q	5.54	− 1° 353	75 *Ceti*	2 27.1	− 1 28
r	5.63	− 3° 336	66 *Ceti*	2 07.7	− 2 52
s	5.64	− 1° 322	70 *Ceti*	2 17.1	− 1 20
t	5.66	− 7° 393	67 *Ceti*	2 12.0	− 6 53
u	5.73	− 1° 377	84 *Ceti*	2 36.1	− 1 08
w	5.76	+ 1° 410		2 12.8	+ 1 17
x	6.00	− 2° 375	63 *Ceti*	2 06.5	− 2 18
y	6.30	− 3° 374	71 *Ceti*	2 20.0	− 3 14
z	6.47	− 5° 438		2 14.6	− 4 48
A	6.71	+ 0° 370		2 10.1	+ 0 15
B	6.8–[1]	− 4° 394		2 20.0	− 4 20
C	7.27	− 3° 372			
D	7.33	− 3° 340			
E	7.86	− 2° 389			
F	8.12	− 4° 379			
G	8.44	− 3° 375			
H	8.65	− 4° 390			
I	8.80	− 3° 371			
J	8.95	− 3° 363			
K	9.35	− 3° 347			
L	9.44	− 3° 355			
M	9.48	− 3° 373			
N	9.99	− 3° 362			

[1] Harvard magnitude 7.06, has 8.5 magnitude companion. Combination of the two assumed 6.8 magnitude.

upon a single comparison star. As a hundredth of a magnitude is of little significance in observations of this kind, the final means have been rounded off to the nearest tenth of a magnitude, but the light-curve, shown in Fig. 1, was drawn with the means taken to hundredths. Evidence of the Purkinje phenomenon shows in the change from opera glass to the three-inch finder.

TABLE XVIII.

Observations of the Brightness of *o Ceti*.

Astronomical Date	G. M. T.	Comparisons	Mag.	Mean
1902				
June 23	$23^h.5$	v = b	3.64	
		v 2 g	3.74	
		a 2 v	3.86	
		v 2 f	3.69	
		v = d	3.86	3.8
27	22.8	b 2 v	3.86	
		f 1 v	4.02	
		v 2 g	3.74	
		v 2 c	3.49	
		v 4 e	3.46	
		d 2 v	4.08	3.8
July 2	22.9	b 2 v 2 e	3.77	
		v = f	3.91	
		g 2 v 2 i	4.14	
		d 2 v 3 m	4.27	4.0
6	22.8	v = e	3.90	
		f 1 v 3 m	4.15	
		d 2 v 2 h	4.08	
		g 2 v 3 i	4.11	4.1
14	22.2	e 3 v 2 m	4.49	
		i 1 v 1 l	4.53	
		v = k	4.62	
		v = j	4.46	4.5
18	23.1	v = k	4.62	
		v = m	4.88	
		j 2 v 3 n	4.70	4.7
22	23.1	v = n	5.05	5.0
29	22.6	v = p ·	5.22	
		n 2 v 2 t	5.36	
29	23.2	m 5 v 5 s	5. 6	5.3
Aug. 4	23.1	v = t	5.66	
		n 2 v 2 s	5.34	
		p 3 v 2 q	5.41	5.4
11	22.7	v = s	5.64	
		v = n	5.73	
		q 2 v 2 r	5.58	5.6
18	23.8	r 2 v 2 x	5.81	
		v = w	5.76	
		s 3 v 3 y	5.97	5.9
25	22.2	v = y	6.30	
		v = z	6.47	
1902				
Aug. 25	$22^h.2$	x 2 v 2 B	6.42	6.4
Sept. 3	20.8	B 2 v 2 D	7.06	
		v = A	6.71	6.9
6	21.6	B 2 v 2 D	7.06	
		y 6 v 4 C	6.88	7.0
9	22.5	v 2 C	7.05	7.0
17	19.5	v = B	6.80	
		y 8 v 3 C	6.98	
		v 3 D	7.00	6.9
27	19.8	v = C	7.27	
		v = D	7.33	7.3
Oct. 5	18.5	v = C	7.27	
		E 4 v 2 F	8.04	7.8
8	19.0	E 5 v 2 F	8.05	
		C 2 v 3 G	7.74	7.9
15	19.3	v 2 G	8.22	
		E 5 v 2 F	8.05	8.1
27	19.0	F 3 v 2 J	8.61	
		v 1 H	8.54	
		v 2 I	8.58	8.6
Nov. 11	19.8	v = J	8.95	
		v = I	8.80	
		H 2 v 4 M	8.93	8.9
17	17.8	I 2 v 3 M	9.07	
		J 3 v 6 L	9.11	9.1
24	19.8	J 5 v 5 N	9.47	
		v 4 L	9.00	
		v 2 K	9.13	
		I 2 v 2 M	9.14	9.2
Dec 12	19.5	J 2 v 5 L	9.09	
		v = I	8.80	9.0
24	17.8	J 2 v 2 K	9.15	
		v 5 L	8.89	9.1
190				
Jan. 3	16.8	J 3 v 3 K	9.15	
		v = I	8.80	9.0
29	16.2	v = J	8 95	
		G 2 v 2 H	8.54	8.7
Feb. 28	16.0	V 2 C	7.05	7.0
March 17	15.5	m 5 v 5 q	5.21	5.2

After January 10, 1903, the observer was in residence at Berkeley, and a few observations of brightness were made there with various instruments.

REMARKS.

June 27: Fifth comparison assigned ½ weight on account of interval of 4 grades.

August 18: First of opera glass series.

September 3: Could see v with naked eye.

September 17: First with three-inch finder.

October 5: Identifications certain.

October 8 and 15: Remembered comparison with E and F on October 5.

January 29: Berkeley. One-inch telescope.

February 28: Berkeley. Two-inch telescope.

March 17: Berkeley. Opera glass.

MAY 1, 1903.

ON THE SPECTRUM OF THE AURORA.

By C. Runge.

In his report on the aurora Paulsen[1] compares its spectrum with the spectrum of the bluish light near the cathode of a vacuum tube filled with oxygen and a little nitrogen and monoxide of carbon. Paulsen comes to the conclusion that there is a close connection between the two spectra:

Les tableaux ci-dessus semblent donc révéler un accord intime entre le

Krypton	Intensity	Aurora	Intensity	Oxygen Tube near Cathode	Intensity
				603.5–589.0	1
				598.0	2
587.1	8			589.0–575.0	3
				575.0–553.7	1
				569.3	1
557.0	8	558.0–554.4	10	561.8–556.8	12
556.2	4				
				543.3	1
				534.3	5
				528.7–513.5	1
				526.5	3
				523.0	5
				520.0–518.3	8
				508.0–506.5	1
				500.0	3
				496.0	2
				492.0	1
				485.5–480.0	5
				476.2	1
467.1	2	470	10	470.2	10
462.4	1	463	10	464.8	10
				458.8	1
		455	10	456.8	1
				450.5	2
450.2	4				
446.4	5	449	10	448.8	2
445.4	4				
440.0	1	441.5–439.0	1	441.6	10
				437.5	1
437.6	3			436.5	2
436.2	2	436.0–430.5	1	435.2–433.6	10
432.0	4				
431.9	2			431.7	2
427.4	4	428.5–425.0	10	428.5–426.0	10

[1] *Rapports présentés au congrès international de physique*, **3**, 438. Paris, 1900.

spectre de l'aurore boréale et celui de la lumière qui entoure la cathode d'un tube contenant de l'oxygene et de l'azote.

The conclusion seems to me misleading. For if we compare the spectrum of the aurora with the spectrum of krypton, the coincidences are at least as striking as in the case considered by Paulsen. In the preceding table the three spectra are written side by side as far as krypton lines have been observed. The first column gives the spectrum of krypton in a vacuum tube without Leyden jar and spark-gap, according to my observations. The second column contains the spectrum of the aurora, and the third the spectrum near the cathode of an oxygen tube, both as given by Paulsen. The wave-lengths are given in $\mu\mu$.

I do not maintain that these coincidences prove the spectrum of the aurora to be that of krypton. I wish, on the contrary, to draw the inference that these comparisons of spectra have very little value as long as the wave-lengths of the auroral lines are not measured more accurately. The only auroral line which has been measured with a considerable amount of accuracy is the green line, and here the coincidence seems to be in favor of krypton, as I pointed out some years ago.[1]

In Scheiner's *Astronomical Spectroscopy*, translated, revised, and enlarged by E. B. Frost, the following determinations of the wave-length of the green line are considered the most accurate:[2]

	λ		λ
1867, Ångström	5568	1874, Huggins	5572
1872, Vogel,	5572	1880, Copeland	5573
1872, Wijkander	5573	1882, Gyllenskiöld	5569
1873, Lemström	5570	1894, Campbell	5571.6

My determination of the green krypton line is:

$$\lambda = 5570.417, \text{ mean error } 0.015.$$

The broad band at λ561.8–556.8 that Paulsen has measured in the spectrum of the oxygen tube is probably the green band of carbon monoxide.

KIRCHRODE BEI HANNOVER,
October 1903.

[1] *Nature*, **59**, 29, 1898, p. 326.

[2] I have reduced the wave-lengths to Rowland's scale.

TEN STARS WHOSE RADIAL VELOCITIES VARY.

By EDWIN B. FROST and WALTER S. ADAMS.

THE systematic observations of stars having spectra of the *Orion* type, which have been a part of our program during the past two years, continue to yield, as an interesting by-product, a large proportion of spectroscopic binaries. The present list brings the number so far found with the Bruce spectrograph up to twenty-three (aside from four having spectra of other types). We have at present obtained the minimum number of three good plates for only sixty-three of these *Orion* type stars, so that the ratio of those whose radial velocities are variable is at the least greater than 1 : 3 for those so far observed by us. The fact must be considered that the lines in the spectra of many of these stars are so broad and ill-defined that only rough determinations of radial velocity are possible, whence variations of small amplitude must escape detection with the present appliances. Further, the interval of time covered by our observations, particularly of the fainter stars included in our present list, is too short to permit the recognition of variations having periods longer than a few days or weeks. Finally, three observations are by no means sufficient to establish the constancy of the radial velocity of any star, even during a short interval of time. Accordingly the striking inference must be drawn that one out of every two or three stars with spectra of the *Orion* type constitutes a dual (or perhaps multiple) system.

Most of the spectrograms referred to below were obtained with the dispersion of one prism and with the triple camera lens of 607 mm focus. They are designated as series IB, followed by the current number. Since our last communication, in the June number of this JOURNAL, the outer temperature case has been altered by the insertion of two doors, so that it can be used with one prism or two or three prisms, as may be desired, and the temperature can be maintained practically as steadily as when

all doors are closed and the three prisms are used according to the original design of the spectrograph.

Reference has already been made[1] to the advantages derived from the use of low dispersion for stars with this type of spectrum. It would probably not be too much to say that fully ha' of the stars in the list below can be studied to better advantage with one prism than with three. A notable illustration of this is *ι Orionis*, in the spectrum of which, upon negatives taken with high dispersion, the lines are barely recognizable as very faint brightenings in the continuous spectrum, and are practically immeasurable. Accordingly, while it may appear that in the list of measures given below rather large differences are to be found between the values obtained by the different observers from the same plate, these differences are to be considered as due rather to the inherent character of the spectra than to the fact that insufficient scale has been employed to enable accurate measurement.

π Andromedae ($\alpha = 0^h\ 32^m$; $\delta = +33°\ 10'$; Mag. $= 4.4$).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 92	1903, Sept. 25	$17^h\ 31^m$	F.	− 6	+ 3	2	5	− 2
106	Oct. 10	14 7	A.	+31	+33	4	3	+32
129	Oct. 17	19 30	F.	+58	+62	5	5	+60

The lines in the spectrum of this star are rather sharper than in the case of most stars of this class. The first plate is poor, but the other two are rated in our notes as good.

ξ Cassiopeiae ($\alpha = 0^h\ 37^m$; $\delta = +49°\ 58'$; Mag. $= 4.8$).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 107	1903, Oct. 10	$14^h\ 50^m$	A.	−20	− 8	3	3	−14
153	Oct. 24	17 34	A.	−33	−37	5	3	−35
175	Nov. 7	14 35	F.	0	− 9	3	5	− 5

[1] "Some Miscellaneous Radial Velocity Determinations with the Bruce Spectrograph," ASTROPHYSICAL JOURNAL, **18**, 67, 1903.

The lines in the spectrum of this star, although not excessively broad, are very ill-defined and diffuse, and the measures are probably subject to more uncertainty than those for any star in the list.

o Orionis ($\alpha = 5^h\ 17^m$; $\delta = -0°\ 29'$; Mag. $= 4.6$).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
C 18	1903, Feb. 19	$15^h\ 59^m$	A.	....	+31	..	4	+31
C 26	Feb. 25	13 33	F.	+29	....	4	..	+29
A 413	Mar. 6	14 25	A.	....	+31	..	6	+31
IB 75	Sept. 5	21 51	A.	+18	+21	4	5	+19
87	Sept. 18	21 46	A.	+29	+34	6	6	+32
103	Sept. 26	21 55	A.	....	+27	..	6	+27
114	Oct. 10	20 34	A.	....	+32	..	3	+32
133	Oct. 17	22 47	F.	....	+27	..	7	+27
156	Oct. 24	20 05	A.	....	+33	..	5	+33

The values given by C 18 and C 26 of the above list are entitled to low weight in view of the quality of the spectra. The chief evidence of variation in the star's velocity is furnished by IB 75: the excellent character of this plate and the satisfactory agreement of the two sets of measures upon it lead us to the conclusion that the variation is real. The spectrum is very well adapted, for a star of this type, to accurate measurement, most of its lines, in particular those due to helium, being strong, narrow, and well defined.

χ *Aurigae* ($\alpha = 5^h\ 26^m$; $\delta = +32°\ 8'$; Mag. $= 5.0$).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 73	1903, Sept. 5	$19^h\ 48^m$	A.	+31	+25	5	5	+28
112	Oct. 10	18 46	A.	+15	+ 9	5	6	+12
120	Oct. 16	20 16	A.	+11	+15	5	5	+13

The spectrum of this star is similar to that of *o Orionis*, although its lines are rather less sharply defined. λ 4267 is exceptionally strong.

ι Orionis ($\alpha = 5^h\ 30^m$; $\delta = -5°\ 59'$; Mag. = 3.0).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 76	1903, Sept. 5	$22^h\ 29^m$	A.	+18	+23	2	4	+21
97	Sept. 25	21 58	F.	+44	+35	4	4	+40
104	Sept. 26	22 33	A.	+59	+55	2	3	+57
134	Oct. 17	23 19	F.	....	+35	..	3	+35
147	Oct. 23	23 37	F.	+42	+41	3	3	+42
157	Oct. 24	20 38	A.	....	....	..	..	....
167	Oct. 30	20 00	A.	+89	+91	2	2	+90

The spectrum of this star appears to be decidedly complex. In the case of the majority of the plates the helium lines and $H\gamma$ consist of exceedingly broad and diffuse lines upon which are superposed maxima sometimes to the number of two or three, and usually of considerable intensity. The effect of these is greatly to complicate the determinations of velocity. Sufficient evidence has not yet been obtained to determine whether these maxima are due to the other member or members of the system producing the variation in velocity, or to physical conditions in the star. The determinations of velocity given in the table are, in all cases, derived from the broad diffuse lines, although it has also been our practice to measure the position of the various maxima as well. In the case of IB 157, however, the complication is so great that it has seemed best to us to omit the value obtained from it until further study of the star's spectrum has enabled us to form more definite conclusions as to the relationships involved in the various lines.

ν Orionis ($\alpha = 6^h\ 2^m$; $\delta = +14°\ 47'$; Mag. = 4.4).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			
A 393	1903, Jan. 22	$20^h\ 23^m$	F.	+82	+80	2	4	+81
IB 173	Oct. 31	23 32	F.	+20	+23	6	5	+21
187	Nov. 14	21 31	A.	+11	+13	5	5	+12

The first plate, taken with three prisms and camera A, had such broad and hazy lines that it was laid aside without measure-

ment. The second plate, however, indicated so different a radial velocity that an attempt was made to measure the first, with the above result, which is only very rough. On the second plate measures were made on the carbon line at $\lambda 4267$ and *Mg* $\lambda 4481$, in addition to $H\gamma$ and three helium lines.

18 *Aquilae* ($\alpha = 19^h\ 2^m$; $\delta = +10°\ 55'$; Mag. = 5.1).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 46	1903, June 13	$18^h\ 10^m$	A.	+15	+10	3	3	+12
52	July 4	18 37	F.	−17	−25	3	3	−21
68	Sept. 5	14 12	A.	..	−28	..	4	−28
77	Sept. 12	14 28	A.	− 7	− 3	4	6	− 5

We have found the lines in this star difficult to set upon, and the difference in the values obtained by the two observers is unusually large.

2 *Lacertae* ($\alpha = 22^h\ 17^m$; $\delta = +46°\ 2'$; Mag. = 4.8).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 64	1903, Aug. 8	$17^h\ 56^m$	F.	− 82	− 89	4	4	− 86
71	Sept. 5	17 43	A.	− 19	− 13	4	5	− 16
	Second Component			−199	−171	3	3	−185
88	1903, Sept. 25	13 27	F.	+ 1	+ 1	4	4	+ 1

The spectrum on the first plate is much fainter than on the other two, but on re-examination it gave indications of the presence of lines due to a second luminous component, which were measurable on the second plate. These additional lines cannot be seen on Plate 88.

6 *Lacertae* ($\alpha = 22^h\ 26^m$; $\delta = +42°\ 37'$; Mag. = 4.6).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 50	1903, June 26	$19^h\ 45^m$	F.	−23	−24	4	3	−24
65	Aug. 8	18 47	F.	−14	−14	4	4	−14
83	Sept. 18	18 6	A.	− 6	0	3	4	− 3

In this spectrum the silicon lines appear in addition to those of hydrogen and helium, but settings could be made on only one of these. All the plates are rated as good.

1 Hev. *Cassiopeiae* ($\alpha = 23^h\ 25^m$; $\delta = +58°\ 0'$; Mag. = 4.8).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 151	1903, Oct. 24	$15^h\ 48^m$	A.	−58	−75	5	5	−66
168	Oct. 30	21 07	A.	..	−60	..	3	−60
169	Oct. 31	15 27	F.	−75	−65	4	4	−70
177	Nov. 7	16 52	F.	+ 3	− 6	3	3	− 2

Plate 168 was obtained through clouds and is underexposed. The lines in the spectrum are very broad and diffuse, and are perhaps complicated by maxima.

AN *ORION* STAR WITH A GREAT RADIAL VELOCITY.

Five spectrograms have yielded the following values for the velocity of the star:

ξ Persei ($\alpha = 3^h\ 53^m$; $\delta = +35°\ 30'$; Mag. = 4.1).

Plate	Date	G. M. T.	Taken by	Measured by	No. of Lines	Velocity
						km
IB 93	1903, Sept. 25	$18^h\ 27^m$	F.	A.	2	+88
101	Sept. 26	20 38	A.	A.	3	89
119	Oct. 16	19 20	A.	A.	2	80
141	Oct. 23	18 41	F.	A.	2	80
160	Oct. 24	23 17	A.	A.	2	88
					Mean	+85

The spectrum of this star is excessively difficult of accurate measurement, owing to the breadth, and still more to the extremely ill-defined character of its lines. Consequently we do not regard the above range of 9 km in the measures as a real variation. Observations covering a longer interval may, however, show the star to be a spectroscopic binary, and, in view of the very low radial velocities which seem in general to be characteristic of stars having the *Orion* type of spectrum, a result of this nature is, in fact, rather to be expected.

BRIGHT-LINE SPECTRA.

Recent plates which we have obtained of the following stars of the *Orion* class show them to contain bright lines:

c Persei,	$\alpha = 4^h$	1^m;	$\delta = +47°$	$27'$;	Mag. = 4.3.	3 plates by F.
25 *Orionis,*	5	20	+1	45	4.6.	2 plates by F. and A.
β Piscium,	22	59	+3	17	4.6.	4 plates by F.

As is characteristic of the stars with this peculiar variety of the *Orion* type spectrum, the hydrogen lines have a double bright component, which is superposed about centrally on the broader dark line or band. Bright $H\beta$ is especially conspicuous on the plates, partly from its intrinsic intensity, and partly because of the weakness of the continuous spectrum at that region on our plates. Bright $H\delta$ is only faintly visible on the broad absorption line, following the usual decline in intensity of such bright lines as the violet is approached. The helium lines at λ4388 and 4472 and *Mg* 4481 are dark, but are dim and diffuse in each star. The separation of the components of the bright hydrogen lines is least for *β Piscium*, and is very wide for 25 *Orionis*.

Eight plates of *c Persei* were used in the *Draper Catalogue*, and the spectrum was classed as A. Five each were included for 25 *Orionis* and *β Piscium*, which were respectively assigned to classes B and A. The exposure times were probably not suited to bring out the peculiarities of the spectra. These stars were not included among those studied by Miss Maury and by Miss Cannon in Vol. 28 of the *Harvard Annals*.

The determination of the true radial velocity is very difficult for such spectra, but, as far as we have yet measured the plates, we have not obtained certain evidence of a variation of the radial velocities of these three stars.

YERKES OBSERVATORY,
November 15, 1903.

FURTHER OBSERVATIONS ON THE SPECTRUM OF THE SPONTANEOUS LUMINOUS RADIATION OF RADIUM AT ORDINARY TEMPERATURES.[1]

By SIR WILLIAM HUGGINS and LADY HUGGINS.

IN the plate accompanying our paper on the spectrum of the glow of radium bromide,[2] at least seven lines are seen to agree, both in position and in intensity, with corresponding lines in the band spectrum of nitrogen. We called attention to other lines, of which some traces may be detected on the plate, and we suggested that with a longer exposure a more complete spectrum would be obtained. One strong line in the radium bromide glow spectrum, about λ 3914, has no similar line corresponding to it in the band spectrum of nitrogen as given on the plate.

We have since taken photographs, with longer exposures, of two specimens of radium bromide, one prepared by Buchler & Co., and the other received from the Société Centrale de Produits Chimiques. In these photographs lines only faintly glimpsed in our earlier photographs can be seen distinctly. A photograph taken of the French radium bromide with an exposure of 216 hours is reproduced on the accompanying plate.

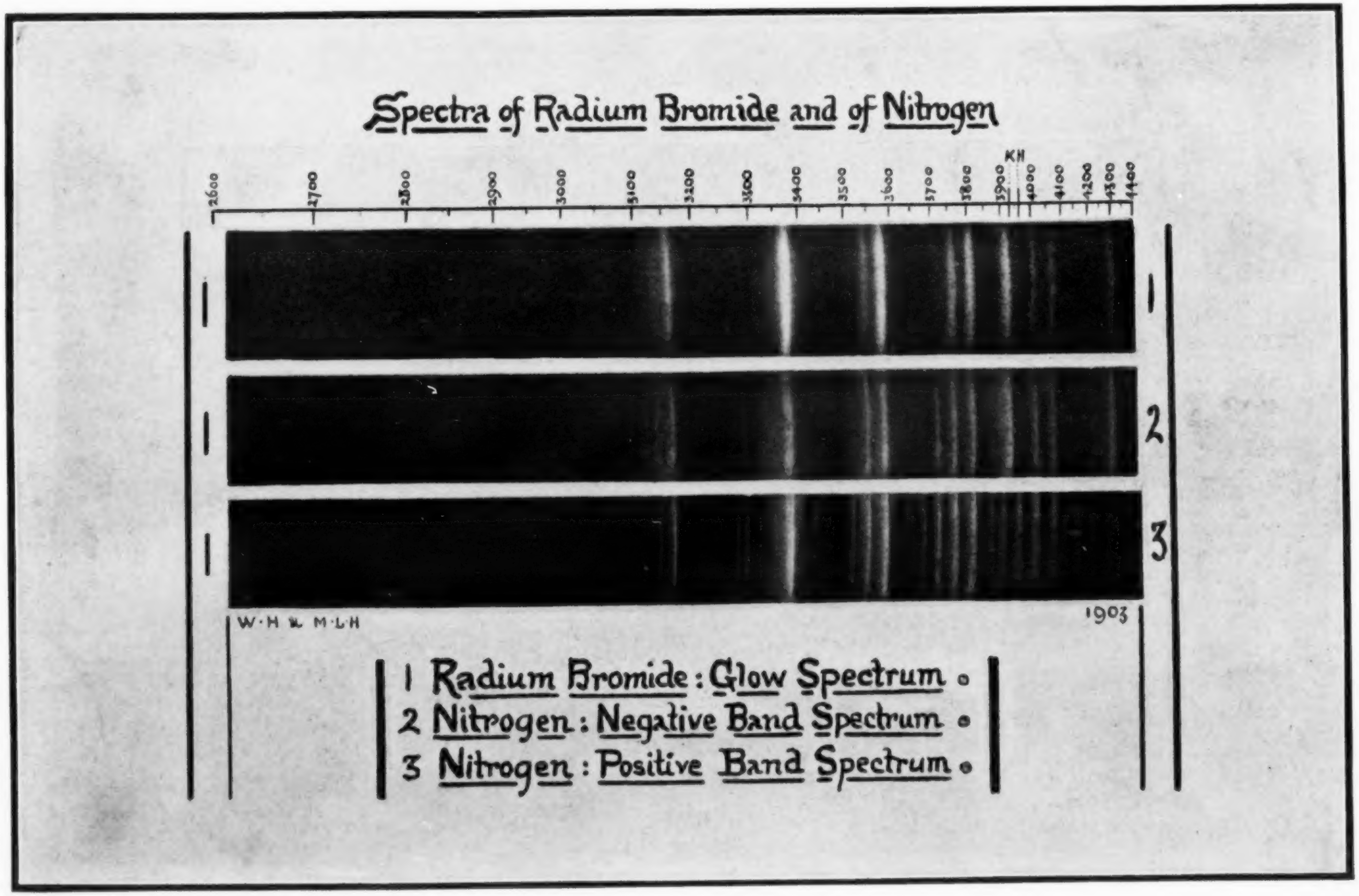
The coincidence of the spectrum with the band spectrum of nitrogen is shown to be even more complete by the presence of a faint trace of the next more refrangible band, beginning at λ 2976.7. In addition, some of the fainter single lines of the nitrogen spectrum now come out in the radium bromide spectrum.

At the same time that the coincidence down to minuter details with the nitrogen band spectrum is brought out, the strong outstanding line, about λ 3914, is now seen to be accompanied by a second, but less intense, outstanding line at about λ 4280; neither of which is present in the ordinary band spectrum of nitrogen, which was the one reproduced on the plate of our first paper.

[1] From advance proofs of a paper communicated to the Royal Society, October 29, 1903.

[2] ASTROPHYSICAL JOURNAL, **18**, 151, 1903; *Proc. R. S.*, **72**, 196, 1903.

PLATE XVII.


Spectra of Radium Bromide and of Nitrogen
2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000 4100 4200 4300 4400
KH
1
2
3
W·H & M·L·H
1903
1 Radium Bromide : Glow Spectrum
2 Nitrogen : Negative Band Spectrum
3 Nitrogen : Positive Band Spectrum

This nitrogen band spectrum is the one distinguished by Deslandres as that of the positive pole, but it appears at all parts of a vacuum tube, and is also produced when a suitable induction coil discharge, without capacity, is taken across air at the ordinary density. The nitrogen spectrum that was measured by Ames was taken by using an end-on vacuum tube closed with a quartz plate; in his list no lines are given at the places of the two outstanding lines in the glow spectrum.

When, however, the spectrum is taken of the aureole about the negative pole of a vacuum tube containing a residuum of atmospheric air, the ordinary, or positive-pole spectrum becomes enriched by a new spectrum of bands; and in this additional spectrum the heads of the two strongest bands in the photographic region, occur at the positions of the two outstanding lines of the radium glow spectrum.[1] On the plate are given, below the more complete radium spectrum now obtained, the ordinary band spectrum of nitrogen, and also the same spectrum enriched with the bands peculiar to the aureole of the negative pole. This latter spectrum corresponds to that of the radium glow. The peculiar conditions, whatever they may be, which determine the presence of these additional negative-pole bands must find their counterpart in the nitrogen molecules when under stimulation by the radium bromide. The additional bands which show themselves in the spectrum of nitrogen when taken from the glow at the negative pole of a vacuum tube are usually believed to be associated with the stimulation of the very rapidly moving corpuscles of the cathode stream. Accordingly the presence of these negative-pole bands in the spectrum of nitrogen when excited by radium naturally suggests whether the β rays, which are analogous to the cathode corpuscles, may not

[1] Deslandres's measures, reduced to Rowland's scale, of the heads of these two bands are λ 3914.4 and 4279.6 (*Thèses*, 1888, Gauthier-Villars, and *Comptes Rendus*, **101**, 1256). Angström and Thalèn give 4281.6 for the less refrangible band (*Nova Acta Upsal.* (3), **9**, 1875). Hasselberg's measure for the head of the less refrangible band is 4378.6 (*Mem. de l'Acad. St. Petersb.*, **32**, No. 15). Percival Lewis on "Some New Fluorescence and Afterglow Phenomena in Vacuum Tubes Containing Nitrogen" (Astrophysical Journal, **12**, 8) found fluorescent nitrogen to give a band spectrum; and, in some conditions of the fluorescence, the most intense bands were those of wave-lengths 3576.9 and 3371.2.

be mainly operative in exciting the radium glow. On this surmise it would be reasonable to expect some little extension of the glow outside the radium itself. We are unable to detect any halo of luminosity outside the limit of the solid radium bromide; the glow appears to end with sudden abruptness at the boundary surface of the radium. It may be that it is only at molecular distances, and at the moment of their formation, that the rays can excite the nitrogen molecules.

As the glow spectrum is produced by the influence of the radium on nitrogen at the atmospheric pressure, it seemed to be of interest tó find out whether the negative-pole spectrum could be obtained in air at the ordinary pressure. It has already been stated that when a suitable discharge of an induction coil, without capacity in the circuit, is taken between electrodes in air, the ordinary band spectrum of nitrogen appears. Separate photographs, therefore, were taken of the parts of the discharge in the close neighborhood of the two electrodes, which were about three-eighths of an inch apart. The bands peculiar to the negative-pole of a vacuum tube were found upon the plate taken of the negative electrode.

As the radium glow consists of light from nitrogen molecules stimulated into luminosity by the presence of the more active radium molecules, it was reasonable to suppose that the bromine molecules, chemically associated with the latter, might also be sufficiently stimulated to reveal their presence by the lines in the spectrum, peculiar to them. Photographs were accordingly taken of the poles of a vacuum tube containing traces of atmospheric air together with bromine vapor. The band spectrum of nitrogen appeared alone upon the plates when no capacity was introduced; but with the intercalation of a jar, the lines of bromine came out in the photopraphs, in addition to the lines of air. The experiment was then repeated at atmospheric pressure by enclosing platinum electrodes in a glass bulb communicating with the atmosphere by a narrow tube. Photographs of the coil discharge taken between them revealed the ordinary band spectrum of nitrogen. A few drops of bromine were then introduced into the bulb, filling it with bromine vapor. Photographs were again

taken of the discharge in the air now heavily laden with bromine, but the spectrum remained precisely the same as before the bromine was introduced, namely, that of nitrogen only.

We find in this experiment possibly a sufficient reason for the absence of any of the lines of bromine in the glow spectrum: it may be that stimulation from the active radium molecules affects preferentially the nitrogen molecule, so that this molecule can be shaken into luminosity by a stimulation which is insufficient to excite the bromine molecule to a comparable extent.

The experiment then suggested itself whether, under similar conditions of discharge, radium itself, when placed upon the electrodes, would be able to show its presence by its characteristic lines in the spectrum of the discharge taken between them. The result was negative; as in the case of bromine, no lines other than those of nitrogen appearing upon the plate. A small jar was then put into the circuit and another photograph taken, when the complete spectrum of radium came out strongly, but without the band spectrum of nitrogen.

If, as suggested by Rutherford, the α rays are connected with helium, the experiment seemed worth making of taking a photograph of the spectrum arising from their bombardment upon a zinc sulphide screen. It seemed possible, though not very probable, that the encounters of these bodies, at the enormous speed at which they travel, with the molecules of air, and their final collision with the screen, might on that hypothesis give rise to some of the radiations peculiar to helium and so produce its spectrum on the plate. Fortunately the strong continuous spectrum due to the fluorescence of the screen ends abruptly in the violet a little before the place, at λ 3889, of the strongest line of helium in the photographic region, and so leaves the spectrum quite free for the detection of this line, even if it were only faintly present. The result of the experiment, so far as concerns helium, was negative; which must not of course be interpreted as excluding the presence of helium, but only as showing that, if present, the conditions are not favorable to the appearance of its spectrum.[1]

[1] M. HENRI BECQUEREL has quite recently investigated the scintillation observed on a phosphorescent screen when excited by radium. He comes to the conclusion:

On the first photograph that was taken, the two strongest lines of the nitrogen band spectrum were faintly seen, but a photograph with a new screen and a longer exposure showed no trace of the nitrogen bands. In the first case it might be that some very minute particles of radium bromide had attached themselves to the screen, and by their independent glow had given rise to the lines of nitrogen which were on the photographic plate.

About one centigram of French radium bromide, which was in the form of small particles, was put into a very small glass tube scarcely larger than was necessary to contain it. The tube was securely closed and left for two months. As the *α* rays being unable to escape, would probably occupy the interstices between the radium bromide particles, it seemed desirable to examine whether as helium, or still in some precedent condition, they would show their presence in the glow spectrum. The tube was exposed, immediately in front of the slit, for 168 hours. The spectrum shows a strong continuous spectrum from the fluorescence of the glass, and faintly the bands of nitrogen, but no other lines with certainty. We intend to photograph again the spectrum of the glow from this tube, after a longer time has passed for an accumulation of the *α* rays, and of the gas-like emanation.

When the radium bromide is covered with a plate of quartz, the continuous spectrum, due to the fluorescence of the quartz, is not only strong, but extends a long way into the ultra-violet. It can be traced on the photograph as far as $\lambda 2500$.

After a few hours the quartz darkens under the action of the radium bromide, the brown stain extending through the complete substance of a plate one-tenth of an inch in thickness. The stain is due probably to the reduction of silicon.

Experiments were made in the hope of throwing light upon the shift found in the photograph of the radium glow spectrum,

(1) "Ce sont les rayons *α* qui provoquent la phosphorescence scintillante;" (2) "Ces faits établissent sinon une démonstration, du moins une grande présomption en faveur de l'hypothèse qui attribuerait la scintillation à des clivages provoqués irrégulièrement sur l'écran cristallin par l'action continue plus ou moins prolongée des rayons *α*." *Comptes Rendus*, 137, 633, 634; October 27, 1903.

reproduced on the plate of our first paper. As subsequent photographs of this spectrum were entirely free from any trace of shift, the shift found on the first plate must have been accidental. Repeated photographs, taken with the spectroscope in different positions, failed to show the smallest trace of shift from flexure. The only suggestion we can make in explanation is that the piece of solid radium bromide accidentally shifted in its cell, so as no longer to be directly under the slit, and in consequence the collimator lens was not wholly filled with light.

The results of the experiments described in this paper would appear to show generally, if analogy with electric stimulation may be assumed, that the radium stimulation, whether we take the operative cause to lie in the β rays, or in the encounters of nitrogen molecules with the active molecules of radium—by which, for the first time, a spectrum of bright bands in the ultra-violet region has been obtained at ordinary temperatures, and without the intervention of an electric discharge—from the very circumstance of its being of such a nature as to give rise to the band spectrum of nitrogen, is not of a kind which can elicit from either the molecules of bromine, or of radium their characteristic line spectra.

The question suggests itself whether or not the same inability may hold in respect of the helium molecule, which is easily stimulated by an electric discharge; we have not as yet made experiments on this point.

Reviews

Lehrbuch der Physik. Von O. D. CHWOLSON. Bd. I, pp. 791. Translated from the Russian into the German by H. PFLAUM. Braunschweig: Vieweg, 1902.

THE appearance of a new compendium of physics, filling no fewer than four octavo volumes, is certain to make one curious as to the features which distinguish it from other treatments of a similar nature. And since in this particular case, alas! no similar treatment exists in the English language, we are driven to the larger German treatises, such as Wüllner and Müller-Pouillet, for a basis of comparison. For, while the *Text-book of Physics* by Poynting and Thomson may well be reckoned in this class, and while, in a very true sense, it will cover the entire field of physics, it is nevertheless largely devoted to the discussion of discrete problems, and begins by omitting the entire subject of dynamics.

As compared with Wüllner's *Lehrbuch*, which may perhaps be taken as a typical, connected discussion of the whole subject, the most striking contrasts are perhaps the following:

1. Chwolson gives a much more elaborate philosophical introduction, devoting more than fifty pages to questions such as the classification of the sciences, the distinction between theoretical, mathematical, and experimental physics, the characteristics of a good hypothesis, etc. The author has evidently a keen appreciation of the unity of his science, for this same philosophical vein runs through the entire volume. To illustrate, the spectrometer, essentially an instrument for measuring angles, and usually handled under the head of optics, here finds discussion in a chapter on "Measuring Instruments," where it logically belongs.

2. As compared with Wüllner or with Violle's *Cours de Physique*, the volume under review contains much more elaborate references to the literature of each topic. These valuable bibliographies are placed at the end of each chapter, and are there grouped under the headings of the sections, so that really each section is provided with its own bibliography. The amount of Russian work here cited will be surprisingly large to those who still imagine that the energies of this

great nation are exclusively devoted to the arts of war and to the care of Siberian exiles.

3. The mathematical discussion is the very simplest — too simple, we venture to think. Differential equations, even the most elementary, are studiously avoided. In America, certainly no student would be reading so advanced a treatment of general physics without the preparation to enjoy more elegant mathematical methods. As illustration may be cited the derivation — or rather the lack of derivation — of the equations for damped vibrations, p. 156.

4. Most American readers will probably agree that some of the chapters are too full. For example, the ninth chapter devotes twelve octavo pages to the "dimensions" of physical quantities. Is it not easily possible to put all the essentials of this subject into one quarter of this space?

Your reviewer is not alone in thinking that a great service would be rendered English-speaking students by any competent physicist who will give them a treatise on general physics, along the lines of Chwolson — a treatise which will fill the great gap lying between the college and university text-books, on one hand, and the great compendium of Winkelmann, on the other hand.

H. C.

A Popular History of Astronomy During the Nineteenth Century. Fourth edition. By AGNES M. CLERKE. London: A. & C. Black, 1902. Pp. 489.

WITH the fourth edition Miss Clerke brings her well-known history down to the summer of 1901. As with previous new editions, fresh material has been wisely chosen and skilfully woven into the text, so that neither its value as a book of reference nor its literary charm has been impaired. With great wealth of material to be sifted, it is really remarkable that so little that is questionable has been incorporated and that so few researches of significance have been overlooked. Perhaps the most important omission is that of Nichols's investigations on the heat-radiation of the stars, which were made during the summers of 1898 and 1900. One has the impression also that German astronomers do not receive their full share of attention. At any rate, the great preponderance of English over German references seems disproportionate to the relative merits of German and English investigators. Of a short list of errors, typographical and otherwise, in the third edition, called

to the reviewer's attention by Dr. Schlesinger, the greater part have been corrected in the fourth edition. Among those that remain might be mentioned that of the parallax of 61 *Cygni*, which is still given as between 0."43 and 0."47, although more recent determinations by Davis, Kapteyn, Wilsing, and others make it practically certain that the average parallax of the two components is less than 0."40. There is still an error in correcting the series contained in footnote 5 on page 71 — the first member being 1½, instead of ½ as given.

The illustrations are much improved in quality and are supplemented by a half-tone of the comet of May 1901, reproduced from a photograph taken at the Cape of Good Hope. To Table IV has been added a list of radial and tangential velocities of selected stars.

S. B. BARRETT.

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DECEMBER 1903

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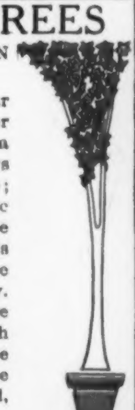

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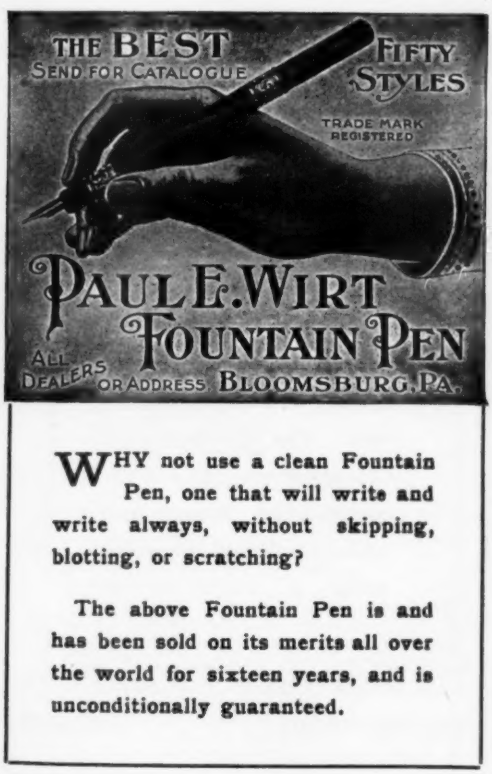
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